GUIDELINES FOR DEVELOPING BESS TECHNICAL STANDARDS IN THAILAND

USAID CLEAN POWER ASIA

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Foreword

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Clean, reliable and secure energy resources are foundational to sustainable economic growth. USAID is helping partner countries expand energy access, promote energy diversification and trade, and strengthen energy security through the U.S. Government's Asia Enhancing Development and Growth through Energy (Asia EDGE) initiative, a whole-of-government initiative seeking to grow sustainable and secure energy markets throughout the Indo-Pacific region. While the region shares some common energy sector challenges, each country's circumstance is unique, and thus, USAID is developing customized tools to expedite countries' transitions to clean and reliable energy technologies. The ***Guidelines for Developing BESS Technical Standards in Thailand*** is one example of how USAID is helping Thailand to make smart energy investment decisions that deliver socio-economic and environmental benefits.

Battery energy storage can bring about greater penetration of renewable energy and accelerate the smooth global transition to clean energy. The surge in lithium-ion battery production has led to an 85 percent decline in prices over the last decade, making energy storage commercially viable. Furthermore, increased investment is bringing new and more innovative energy storage technologies to the market. These innovations are providing promising applications to reduce cost, improve infrastructure management and enable new business models for utilities, grid operators and end-users around the globe, including in Southeast Asia.

Thailand's 20-year Smart Grid Master Plan presents a clear framework for promoting energy storage systems to support the modernization of the power grid and increase the use of renewable resources. The Office of the Energy Regulatory Commission (OERC) initiated an experimental "sandbox" project campaign to support BESS projects to complement renewable energy, for grid modernization, to enable peer-to-peer energy trading, and support micro-grids, among other applications. OERC has also taken the initiative to begin preparing for the development of technical standards to ensure public safety and strengthen grid stability and reliability as the uptake of batteries increases. To address any gaps in existing BESS laws and regulations, OERC and USAID Clean Power Asia, with support from the U.S. DOE National Renewable Energy Laboratory (NREL), leveraged international best practices to inform the guidelines for developing BESS Technical Standards.

USAID is proud to partner with OERC to develop these ***Guidelines for Developing BESS Technical Standards in Thailand*** that reflect global best practices and draw upon real world battery energy storage system experiences. USAID remains committed to working with our partners to assess and invest in clean, smart, and state-of-the-art energy technologies that strengthen energy security and power sustainable economic growth.

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The United States Agency for International Development (USAID) sponsored these ***Guidelines for Developing BESS Technical Standards in Thailand.*** In collaboration with Thailand's Office of Energy Regulatory Commission (OERC), USAID Clean Power Asia and its subcontractor the Hawaii Natural Energy Institute (HNEI), developed the guidelines by building on the findings and conclusions of the National Renewable Energy Laboratory's report on *Key Considerations for Adoption of Technical Codes and Standards for Battery Energy Storage Systems (BESS) In Thailand*. The team reviewed several relevant international standards which include the IEC 62933, NFPA 855, NERC 2018 and 2019 guidelines, IEEE-1547 and soon-to-be-available IEEE P2800, and developed the guidelines which will support OERC and relevant government organizations on developing technical standards for various BESS applications for the country. To complete the guidelines development process, the team hosted a focus group and a stakeholder workshop to collect and incorporate feedback into the document from stakeholders consisting of utilities, policy makers, the private sector, and BESS experts.

In addition to the authors, USAID Clean Power Asia's Chief of Party, Ms. Dana Kenney, and USAID Clean Power Asia RE policy team including Mr. Thanawat Keereepart and Ms. Maythiwan Kiatgrajai, contributed their technical expertise on BESS, while the communications team, Ms. Kwanta Norkum and Mr. Michael Wykoff, helped edit the document.

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ABOUT HNEI

HNEI supported this work in part under funding provided by the U.S. Office of Naval Research (ONR). Founded in 1974, HNEI is a research unit of the School of Ocean and Earth Science and Technology, University of Hawai'i at Manoa that conducts research of state, national and international importance to develop, test, and evaluate novel RE technologies, advanced grid systems, and enabling policies and regulation for the effective integration of RE resources, power system optimization and energy resilience. The Institute leverages its in-house work with public-private partnerships to transfer knowledge and enable the integration of emerging technologies into the energy mix.

GUIDELINES FOR DEVELOPING BESS TECHNICAL STANDARDS IN THAILAND

CONSIDERATION OF INDUSTRY BEST PRACTICES IN THE DEVELOPMENT OF BESS TECHNICAL STANDARDS IN THAILAND

FINAL VERSION

MARCH 25, 2021

Technical Assistance to the Office of Energy Regulatory Commission, Thailand

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LIST OF ACRONYMS

AHJ	authority having jurisdiction
BESS	battery energy storage system
BPS	bulk power system
DER	distributed energy resources
DFIG	doubly fed induction generators
DPV	distributed solar photovoltaic
EDL	Électricité du Laos
EMC	electromagnetic compatibility
EMT	electromagnetic transient
ESS	energy storage systems
FAT	factory acceptance test
FFR	fast frequency response
FMEA	failure mode and effects analysis
FMECA	failure modes, effects and criticality analysis
FRT	fault ride through
FTA	fault tree analysis
GOs	generation owners
HAZOP	hazard operational process
HRC	high rupturing capacity
IBC	International Building Code
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Fire Code
IRC	International Residential Code
NERC	North American Electric Reliability Corporation
NFPA	National Fire Protection Association
NREL	U.S. National Renewable Energy Laboratory
NYBESSG	New York Battery Energy Storage System Guidebook
PCE	power conversion equipment
POI	point of interconnection
POM	point of measurement
PPE	personal protective equipment
PRA	probabilistic risk analysis
SAT	site acceptance test
TOs	transmission owners

EXECUTIVE SUMMARY

A multitude of recently-published guidelines, codes and standards for energy storage system ("ESS") integration have been published and are available to help streamline the process of safely and effectively deploying ESSs for various applications throughout the world. The available publications consider ESSs from a variety of perspectives – from high-level overviews (e.g., IEC 62933), to hazard mitigation (e.g., NFPA 855, CA SED Checklist), to permitting (e.g., NYBESSG), to system integration, design and permitting (e.g., AS/NZS 5139).

Although the spectrum of topics covered by IEC 62933 is perhaps the broadest of all the codes discussed in this report, the details of the requirements are at a relatively high level. However, IEC 62933 includes entire volumes dedicated to Sections II to IV of this report.

ESSs are categorized in a variety of ways, depending on the purpose and perspective of the underlying analysis. Some of the commonly used approaches for classifying ESSs focus on the form of energy used, usage applications, power conversion equipment ("PCE") connections and functions, and system architecture.

The design of an ESS is dependent on the parameters under which it will be required to operate, as well as the location where the system will be installed. Testing of ESS systems is imperative for the assessment of the basic characteristics and performance of ESSs, including detailed testing of unit and electrical parameters. A variety of tests, methods and procedures are available to evaluate an ESSs' compliance with safety, reliability, performance, function and system interconnection requirements.

The specifications of ESSs such as functionality, accumulation subsystem, and PCE depend on the topology of the grid, power demand, and generated power available at the point of connection ("POC"). This requires stakeholders (e.g., planners, owners, operators, constructors, suppliers, and/or aggregators, as well as relevant authorities) to define the application of the planned ESS and specify requirements of the ESS according to the application during the planning phase.

Environmental impacts and conditions such as lightning, seismic activity, water inundation, temperature, barometric pressure, wind, ice/snow, vermin, vibration, dust/smoke, fire, electromagnetic sources, humidity, salt/corrosion, solar irradiation, sediment accumulation and altitude should also be taken into account in the planning and location of an ESS, and appropriate protections and/or measurements should be provided in order to maintain the condition of the space where an ESS is located in accordance with manufacturers' specifications, technology-specific standards, and/or relevant local grid codes, requirements and regulations. Compliance with such requirements should be maintained throughout the ESS installation, commissioning, and performance monitoring processes.

A number of recent case studies have highlighted the inherent dangers posed by ESSs, which generally include electrical, energy, mechanical, electric/magnetic/electromagnetic fields, fire, temperature, explosive gas, chemical and toxic fume hazards. Despite recent efforts to enable safe ESS operation, safety considerations continue to be a key area of focus of ESS-related standards. A common approach for addressing ESS hazards includes three steps: (1) identification of system hazards; (2) risk analysis of system hazards; and (3) measures to reduce risks.

Some of the factors that may impact the level of risk associated with ESSs include POCs, energy capacity, site occupancy, chemistry and application (i.e., residential, commercial, industrial, and utility). In this regard, consideration should be given to having different safety requirements for systems with different sizes and applications. In any case, ESSs should only be installed, operated and maintained by competent persons and in accordance with manufacturers' instructions.

Preventive measures to mitigate ESS hazards generally fall into three categories: (1) inherently safe design; (2) guards and protective devices; and (3) information for end users, and should be designed to avoid or minimize the impacts or hazards, utilizing a layered approach to help prevent minor incidents from escalating into major and potentially catastrophic events.

Preventive measures are also heavily dependent on location, and location and enclosure requirements and recommendations are prevalent in many of the codes that address ESS safety. Factors affecting the suitability of an ESS location may include people in the area, system components, properties and structures, and other external influences. In general, ESSs should not be installed in living areas of dwellings, or near exits, windows, ventilation, appliances, ceiling spaces, wall cavities, roofs, stairways, walkways, evacuation/escape routes or hazardous areas. In addition, ESSs installed outdoors should be separated by a minimum distance from lot lines, public ways, buildings, stored combustible materials, hazardous materials, high-piled storage, and other exposure hazards. However, it may be desirable for codes to allow flexibility in applying their requirements to local municipalities.

In general, ESS rooms and enclosures should be designed, laid out and constructed with an eye toward protecting the ESS from external influences, and protecting against harm to workers, residents, and neighboring inhabitants. Where electrical hazards are present, parts of ESSs should be designed to guard against accidental human contact by means of an enclosure, fencing, guarding or other measures. Safe working practices should be required, including operation and maintenance instructions that provide for secure isolation and earthing of live conductors (where possible), appropriate personal protective equipment ("PPE"), signage, and risk of damage due to mildew or corrosion. Preventive measures against electrical hazards may include earth fault detection; over/under voltage, current and temperature detection; lightning protection; electrostatic dissipation; and fusing. In the event of unintentional islanding, the ESS should be designed to automatically disconnect from the grid.

Other types of hazards common to enclosures such as mechanical, explosion, fire and chemical hazards should be appropriately mitigated through measures such as structural requirements, safety interlocks, robust handles, and mounting means, means to contain parts in the event of an explosion or mechanical failure, ventilation, explosion control, detection systems/sensors/alarms, thermal insulation, and partitions, spacing, and spill control. Adequate end-user information is also critical for ensuring safety during ESS operation, maintenance, and repairs, and generally includes training, labels, signage, and manuals (e.g., separation and shutdown procedures).

The proliferation of inverter-based resources is also giving rise to new interconnection requirements and guidelines, at both the transmission and distribution levels. At the transmission level, Thailand's 2019 EGAT Code already includes some requirements for inverter-based resources, but consideration should be given to supplementing those requirements based on guidance published by NERC in 2018 and 2019, as well as the forthcoming IEEE P2800 standard (once it becomes available). At the distribution level, consideration should be given to updating Thailand's 2015 MEA Code and 2016 PEA Code to incorporate new requirements included in the recently-published IEEE 1547-2018 standard – namely in the areas of voltage and frequency disconnection, ride-through, volt-watt, frequency-watt, volt-var, overvoltage contribution and ramp rate functions.

As the energy storage landscape continues to evolve in Thailand and throughout the world, there will undoubtedly be new developments in ESS technology and best practices. Toward that end, standards, codes, and guidelines ultimately adopted based on this report may need to be updated from time to time, as ESS technologies advance, and become more widely deployed and operated in different contexts.

I. INTRODUCTION

In its October 2020 report titled *Key Considerations for Adoption of Technical Codes and Standards for Battery Energy Storage Systems in Thailand* ("NREL Report"), the U.S. National Renewable Energy Laboratory ("NREL") discussed the growing need for battery energy storage system ("BESS") codes and standards to safely address rapidly increasing deployment of new BESS technologies throughout the world in general, and in Thailand, in particular. As noted by NREL, Thailand currently does not have approved guidelines for BESS interconnection and development, and therefore has been approving such implementations on a case-by-case basis. Developing guidelines, codes and standards for BESS integration may streamline the process of deploying BESSs for various applications as envisioned by policymakers and regulators in Thailand, as well as support increased deployment of renewable energy in furtherance of Thailand's renewable energy goals and reduce overall integration cost and operational risk.

Toward that end, the NREL Report surveyed global best practices on BESS safety and technical standards from several jurisdictions, including Australia, New York and California, and then applied them in the context of key considerations relevant to Thailand. This report builds and expands on the findings and conclusions of the NREL Report, taking into account two additional publications: (1) the International Electrotechnical Commission's ("IEC") International Standard 62933 on Electrical Energy Storage Systems ("IEC 62933"); and (2) the National Fire Protection Association's ("NFPA") Standard 855 for the Installation of Stationary Energy Storage Systems ("NFPA 855").

This report also reviews guidance on best practices for inverter-based resources from the perspectives of transmission-level interconnections and distribution-level interconnections. The discussions on the requirements and guidelines for the transmission-level interconnections consider three publications: (1) the North American Electric Reliability Corporation's ("NERC") *Reliability Guideline – Bulk Power Systems-Connection Inverter-Based Resource Performance* ("NERC 2018 Guideline");[1] (2) NERC's *Reliability Guideline – Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources* ("NERC 2019 Guideline");[2] and (3) the Institute of Electrical and Electronics Engineers' ("IEEE") IEEE P2800 standard, which is currently under development.[3]

With respect to distribution-level interconnections, this report provides high-level assessments of the *Regulation of the Metropolitan Electricity Authority on the Power System Network Connection Code B.E.2558* ("MEA Code") and *Provincial Electricity Authority's Regulation on the Power Network System Interconnection Code B.E.2559* ("PEA Code") in comparison to a proposed grid code for Électricité du Laos' ("EDL") *Distributed Solar Photovoltaic Generating Facility Interconnection Standards* ("EDL Code"),[4] which is based on IEEE 1547-2018.[5]

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[1] The NERC 2018 Guideline is available at: https://www.nerc.com/comm/%E2%80%8COC_Reliability_Guidelines_DL/Inverter-Based_Resource_Performance_Guideline.pdf.

[2] "BPS" refers to the bulk power system. The NERC 2019 Guideline is available at: https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf.

[3] Information regarding the IEEE P2800 standard is available at: https://standards.ieee.org/project/2800.html. The current publication forecast is early 2022, possibly December 2021.

[4] The proposed EDL Code provides general technical guidelines, requirements and procedures. For convenience, a copy of a document that reflects Grid***START***'s recommended changes to the EDL Code is provided as Appendix 1 to this report.

[5] For additional discussion of IEEE 1547-2018, see *Perspectives on Adoption of IEEE 1547-2018*, available at:

The publications referenced above are voluminous, and their scopes cover a broad variety of topics from a variety of different perspectives. In this regard, it should be noted that this report is not intended to serve as a stand-alone document, but rather as a tool for topically identifying and locating (by citation) the key provisions as they relate to the latest guidance on ESS-related considerations. Figure 1 depicts a general usage example of this report. Given the differing focuses of the publications referenced herein, brief overviews of the standards are furnished below to provide context.[6]

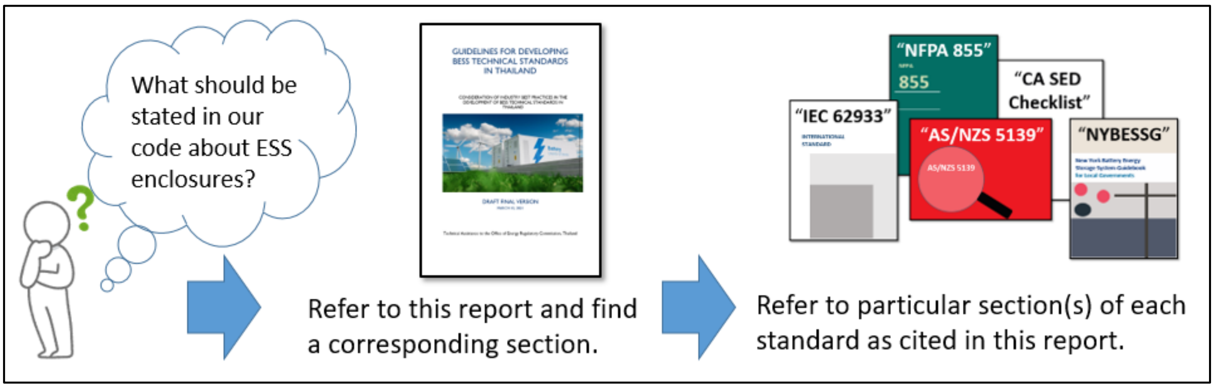

Figure 1. General usage example of this report

A. IEC 62933

Published in 2018, IEC 62933 is comprised of six volumes covering a spectrum of ESS-related topics, including vocabulary (Part 1); general specifications for unit parameters and testing method (Part 2-1); general specifications for planning and performance assessment (Part 3-1); guidance on environmental issues (Part 4-1); safety considerations for grid-integrated ESSs in general (Part 5-1); and safety requirements for electrochemical-based ESSs (i.e., BESSs) in particular (Part 5-2). Although the spectrum of topics covered by IEC 62933 is perhaps the broadest of all the codes discussed in this report, the details of the requirements are at a relatively high level.[7] That being said, the volumes of IEC 62933 that address unit parameters, testing methods, planning and performance assessments (namely Parts 2-1 and 3-1) are generally more comprehensive on these topics than the other publications referenced in this report, and may serve as a useful starting point for purposes of defining, selecting and testing ESSs. For example, IEC 62933 includes detailed methodologies, procedures, diagrams and equations for testing unit parameters and system performance (see Part 2-1 § 6).

https://www.nrel.gov/grid/ieee-standard-1547/reliability-perspectives.html.

[6] It should be noted that the standards described below reference and incorporate other international and national standards including publications by Underwriters Laboratories (e.g., UL 9540), the Institute of Electrical and Electronics Engineers (e.g., IEEE 1547) and the National Electric Code (e.g., NEC 480). A listing of some of those standards is provided in Table 1 of the NREL Report. This report is not intended to be a survey of every global or national standard referenced therein. Rather, the scope of this report is intended to survey a subset of key standards and codes that have arisen and/or evolved around the globe as a result of recent developments in the specific context of energy storage systems.

[7] Published in 2019, IEEE Std. 2030.2.1, *IEEE Guide for Design, Operation, and Maintenance of Battery Energy Storage Systems, both Stationary and Mobile, and Applications Integrated with Electric Power Systems* ("IEEE 2030.2.1"), is another source of international guidance that has been developed to address the design, operation and maintenance of BESSs – albeit at a significantly higher level. Although referenced here for completeness, in order to reduce duplication, further references to IEEE 2030.2.1 are not included in this report.

B. NFPA 855

Published in 2020, the general focus of NFPA 855 is on mitigating the hazards posed by ESSs (e.g., fire, explosion and toxic fume hazards) for end-users, neighboring inhabitants and neighboring structures. Many of the requirements included in NFPA 855 are substantially similar or identical to recently-amended provisions from the International Fire Code ("IFC"), International Building Code ("IBC") and International Residential Code ("IRC"), which as discussed below, are specifically referenced in the New York Battery Energy Storage System Guidebook. Given its focus on safety, NFPA 855 should be considered as a key resource in the development of codes for ESSs installed in or near areas occupied by humans – particularly in urban settings such as New York. By way of example, NFPA 855 generally prohibits the installation of ESSs on floors of buildings that cannot be accessed by fire department laddering capabilities (see § 4.3.9).

NFPA 855 also includes chapters specifically dedicated to system interconnections, commissioning, operation and maintenance, decommissioning, electrochemical energy storage systems, capacitor energy storage systems, fuel cell energy storage systems, storage of used or off-specification batteries, and dwellings and townhouse units.

C. New York Battery Energy Storage System Guidebook

Published in 2020, the New York Battery Energy Storage System Guidebook ("NYBESSG") is designed to help local governments understand and develop a BESS permitting process to ensure efficiency, transparency, and safety in their local communities. The guidebook consists of four chapters:

1) a "Model Law" that lays out procedural frameworks and substantive requirements for residential, commercial and utility-scale BESSs, with built-in flexibility to accommodate local circumstances;
2) a "Model Permit" establishing minimum submittal requirements for electrical and structural plan review for residential and small commercial BESS;
3) a BESS "Electrical Checklist" to serve as a guideline for field inspections of residential and small commercial BESSs; and
4) a "2019 Energy Storage System Supplement" that amends New York's uniform fire, building and residential codes to implement the latest safety considerations for energy storage systems included in the IFC, IBC and IRC.[8]

As noted above, many of the provisions in the NYBESSG are similar or identical to provisions in NFPA 855.

D. AS/NZS 5139

Published in 2019, Australian/New Zealand Standard 5139 on *Electrical installations – Safety of battery systems for use with power conversion equipment* ("AS/NZS 5139") provides manufacturers, system integrators, designers and installers with requirements and other

[8] The NYBESSG is available at: https://www.nyserda.ny.gov/All%20Programs/Programs/Clean%20Energy%20Siting/Battery%20Energy%20Storage%20Guidebook.

information related to the safe installation of battery systems connected to power conversion equipment ("PCE"). The organization of AS/NZS 5139 includes installation, commissioning, and documentation requirements for three general categories of battery systems:

1) "Pre-assembled integrated battery energy storage systems;"
2) "Pre-assembled battery equipment;" and
3) "Battery systems and BESSs not conforming to *Best Practice Guide: battery storage equipment – Electrical Safety Requirements.*"

Although relatively narrower in scope than the other codes above, AS/NZS 5139 includes significantly more detailed requirements and information on topics such as system integration, design and installation. As an example, AS/NZS 5139 provides detailed requirements, specifications and diagrams for the layout and configuration of battery system rooms (see § 6.2.6.2). Technical guidance at the level of detail set forth in AS/NZS 5139 may prove particularly useful for stakeholders involved in ESS design and installation.

E. California SED Checklist

As noted in the NREL Report, similar to Australia and New York, California relies on a combination of international and national codes to provide safety best practices for the installation of energy storage. To avoid duplication, the specific provisions utilized in California are not cited in this report. However, the California Safety and Enforcement Division has also developed a Safety Inspection Checklist ("CA SED Checklist") that provides a set of guidelines for documentation and safe energy practices.[9] Where applicable, references to the CA SED Checklist are included in this report.

F. Interconnection Standards

Published in September 2018, the NERC 2018 Guideline provides recommended steady-state and dynamic performance characteristics for inverter-based resources based in part on lessons learned from disturbance analyses following fault events that were caused by wildfires in the western United States in 2016 and 2017.[10] Currently under development, the IEEE P2800 standard effort is establishing a performance-based standard. To bridge the gap between the current state and future development and adoption of the IEEE P2800, the NERC 2019 Guideline (published in September 2019) includes recommended improvements.

In coordination with EDL, the Hawaii Natural Energy Institute's Grid***START*** group recently supported the creation of a proposed EDL Code in order to align EDL's new distribution-level interconnection requirements with industry best practices, including IEEE 1547-2018. The proposed EDL Code provides general technical guidelines, requirements and procedures to facilitate the interconnection and parallel operation of distributed solar photovoltaic ("DPV") generating facilities

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[9] The CA SED Checklist is available at: https://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/Safety/Risk_Assessment/SED%20Safety%20Inspection%20Checklist%20Final%20042717.pdf.

[10] Subsequent disturbances that occurred in 2018 have been addressed by NERC in its *April and May 2018 Fault Induced Solar Photovoltaic Resources Interruption Disturbances Report, Southern California Events: April 20, 2018 and May 11, 2018, Joint NERC and WECC Staff Report* (January 2019), available at: https://www.nerc.com/pa/rrm/ea/April_May_2018_Fault_Induced_Solar_PV_Resource_Int/April_May_2018_Solar_PV_Disturbance_Report.pdf.

with the EDL distribution system. Serving as the foundation for the proposed EDL Code, the recently-published IEEE 1547-2018 standard provides general requirements for distributed energy resource ("DER") interconnections.

G. Organization of this Report

Given the broad scope of the topics covered in IEC 62933, the remainder of this report is generally organized in a similar fashion. Part II of this report discusses general specifications of ESSs and testing methods. Part III discusses ESS planning. Part IV discusses performance assessments. Part V discusses ESS safety issues (including safety issues specific to BESSs). Part VI discusses ESS interconnections at the transmission-level and distribution-level. Where a code other than IEC 62933 provides additional information, supplemental discussion (and supporting citations) is provided in the corresponding part. Issues that appear particularly applicable in the context of Thailand are also identified and discussed throughout this report. The following table shows topics covered in Parts II to VI of this report.

Table 1. Topics Addressed in Each Section of this Report

Sections	Covered Topics
Part II: General specifications of ESSs and testing methods	A. ESS Classification B. Parameters C. Tests and Testing Methods
Part III: ESS Planning	A. System Environment B. System Sizing and Selection C. Functional System Performance
Part IV: Performance assessments	A. Installation Phase B. Commissioning Phase C. Performance Monitoring Phase
Part V: ESS safety issues including safety issues specific to BESSs	A. General Guidelines for ESS Safety B. Hazard Considerations C. Risk Assessment D. Risk Mitigation Measures E. System Safety Validation and Testing F. Guidelines and Manuals
Part VI: ESS interconnections at the transmission-level and distribution-level	A. Transmission-Level Interconnections B. Distribution-Level Interconnections

It should be noted that the various publications discussed above use different definitions to describe different types of systems. For example, IEC 62933 refers to systems that convert/store electrical energy as "electrical energy storage systems," "EES systems," or "EESS." As a second example, AS/NZS 5139 distinguishes between "pre-assembled battery systems" and "pre-assembled BESSs." To avoid confusion, this report utilizes the term "**Energy Storage System**" (or "**ESS**") as defined in NFPA 855 § 3.3.9 to mean "[o]ne or more devices, assembled together, capable of storing energy in order to supply electrical energy at a future time to the local power loads, to the utility grid, or for grid support." In the case of any ESS that converts and stores chemical energy to electrical energy and vice versa (referred to in NFPA 855 § 3.3.9.1.1 as an "electrochemical energy storage system"), this report uses the term "**battery energy storage system**" or "**BESS**." Other terms not defined in this report should be read according to their meanings as defined in the referenced sources.

It should also be noted that some of the publications discussed in this report are subject to copyright restrictions and/or other terms of use. As a result of such restrictions, this report is designed merely to serve as a roadmap for locating the referenced material. Where the referenced publications are not publicly available, it is highly recommended that users of this report obtain copies of those materials from the original publishers.

II. ESS SPECIFICATIONS AND TESTING METHODS

Although ESS testing is addressed to varying degrees in the standards surveyed in this report, the discussion of testing in IEC 62933 (which includes an entire volume (i.e., Part 2-1) on ESS specifications and testing methods) is perhaps the most comprehensive. In line with IEC 62933 Part 2-1, this Part II of this report addresses the classification, general structures, and parameters of ESSs and various testing methods and procedures. While the majority of the discussion below applies to ESSs in general, specific references to BESSs are also included as it relates to classification of applications, system configuration, and requirements for grid interconnections.

A. ESS Classification

ESSs are categorized in a variety of ways, depending on the purpose and perspective of the underlying analysis. One of the more widely used approaches for classifying ESSs is to focus on the form of energy used. For example, IEC 62933 (see Part 2-1 § 4.2, Part 3-1 § 5.5.1.2) classifies ESSs according to five general forms of energy used in accumulation subsystems: (1) mechanical; (2) electrochemical; (3) chemical; (4) electrical; and (5) thermal (see also NFPA 855 Annex D.1).

ESSs are also commonly categorized based on their usage applications. For example, IEC 62933 identifies the following three general ESS applications: (A) short-duration; (B) long-duration; and (C) emergency power (see Part 2-1 § 4.2, Part 3-1 § 5.5.1.2). Short duration (i.e., "Class A") applications represent ESSs with duty cycles less than one hour per cycle with applications such as frequency regulation, load fluctuation reduction, and voltage regulation. Long duration (i.e., "Class B") applications cover ESSs utilized for peak shaving and peak shifting, with duty cycles more than one hour per cycle. Emergency power (i.e., "Class C") applications cover ESSs that function as back-up power for electric power grids or microgrids in case of an emergency (see IEC 62933 Part 2-1 §§ 4.2-4.5 and 6.3.1). To achieve various functionalities, an ESS may have a combination of applications including multiple classes (e.g., Class A and Class C) with different operation times (see IEC 62933 Part 3-1 § 5.5.1.2).

NFPA 855 Annex D presents in-depth discussions of various types of ESS applications by providing detailed information about applications of ESS technologies that are not covered in the standard (e.g., various mechanical ESSs and superconducting magnetic ESSs). It also includes a chart depicting a generalized comparison of storage technologies and their applications (adopted from U.S. Department of Energy) and a table showing different types of ESSs for different applications in relation to their feasibility and need for future research and development (adopted from Fraunhofer Institute for Solar Energy Systems).

An ESS can also be classified based on the manner in which its PCE is connected to the electrical system. For example, Section 2.3.1 of AS/NZS 5139 identifies three types of BESSs according to the following PCEs and their connections: (1) a PCE that is connected to DC application circuit and included in a BESS; (2) a PCE that is connected to AC (or DC) system and separated or isolated from a BESS; and (3) a PCE that is connected to AC (or DC) system and not separated or isolated from a BESS.

Another approach for classifying ESSs is to focus on PCE functions. For example, AS/NZS

5139 distinguishes between the following three functions: 1) voltage manipulation such as DC to DC converters or AC to DC battery chargers; (2) DC/AC conversion such as stand-alone inverters, multiple mode inverters, or grid-connected inverters; and (3) system input/output DC controller.

Yet another approach for classifying ESSs considers system architecture. In this regard, IEC 62933 describes and illustrates two typical architectures of ESSs depending on whether an auxiliary subsystem is fed internally or from another feeder through an auxiliary point of connection ("POC") (see Part 2-1 § 5.1.4, Part 3-1 § 4.2). In addition, Section 4.2 of IEC 62933 Part 3-1 provides specifications of ESS subsystems, which include accumulation subsystems (see § 4.2.1), power conversion subsystems (see § 4.2.2), auxiliary subsystems (see § 4.2.3), and control subsystems (see § 4.2.4). In the case of a BESS, AS/NZS 5139 § 2 similarly presents diagrams of general functional configuration of BESSs (see § 2.1), key components of BESSs (see § 2.2.4), and typical battery system components (see § 2.2.5). AS/NZS 5139 § 2.2.6 provides four additional figures to demonstrate various possible battery system types.

B. Parameters

The design of an ESS is dependent on the parameters under which it will be required to operate. As described below, two of the commonly considered types of operating parameters include: (1) unit parameters (see IEC 62933 Part 2-1 § 5); and (2) electrical parameters (see IEC 62933 Part 3-1 § 5.4).

The design of an ESS is also impacted by the environmental conditions in the location where the system is installed. Further discussion of environmental impacts to ESSs is provided in Section III.A.2 below.

1. Unit Parameters

For the assessment of the basic characteristics and performance of ESSs, IEC 62933 requires the unit parameters of all ESSs to be tested at a POC under standard testing conditions (see Part 2-1 §§ 5.1.3 and 6.2). IEC 62933 Part 2-1 § 5.1.4 provides a definition of the POC, and § 5.2 defines the following unit parameters:

- nominal energy capacity (Wh);
- input and output power rating including active power (W), reactive power (var), and apparent power (VA);
- roundtrip efficiency (%);
- expected service life (years, duty-cycles);
- system response (step response time (s) and ramp rate (W/s));
- auxiliary power consumption (W);
- self-discharge of ESS (Wh/h);
- voltage range (V); and
- frequency range (Hz).

In addition to identifying the unit parameters above, the sign conversion of active power and reactive power, as well as an example of active power and reactive power characteristics, are shown in a figure (see IEC 62933 Part 2-1 §§ 5.2.2.2-5.2.2.4). IEC 62933 Part 2-1 § 5.2.3 provides formulae to define roundtrip efficiency according to the two typical ESS architectures described in § 5.1.4. To illustrate the linear ramp rate, a formula and a figure are presented in § 5.2.5.2.

2. Main Electrical Parameters

Electrical parameters affect system performance at the POC and potentially at the auxiliary POC as well.[11] IEC 62933 Part 3-1 § 5.4 provides descriptions of some of the main electrical parameters and points of attention, with specific requirements and considerations to be taken into account when measuring the values. References to other standards and codes for further information are also provided in Section 5.4. The main electrical parameters identified in IEC 62933 include:

- rated input and output power (see Part 3-1 § 5.4.2; see also Part 1 § 4.4.6 for general definitions, and Part 2-1 § 5.2.2 for definitions as unit parameters);
- minimum duration input and output power (see Part 3-1 § 5.4.3);
- rated energy capacity (see Part 3-1 § 5.4.3);
- response time parameters (see Part 2-1 § 5.2.5.1);
- auxiliary power consumption (see Part 3-1 § 5.4.4);
- self-discharge (see Part 3-1 § 5.4.5);
- roundtrip efficiency (see Part 3-1 § 5.4.6);
- duty cycle roundtrip efficiency (see Part 3-1 § 5.4.7);
- recovery times (see Part 3-1 § 5.4.8); and
- end-of-service life values (see Part 3-1 § 5.4.9).

C. Tests and Testing Methods

Various types of tests, methods and procedures can be used to evaluate an ESS's compliance with safety, reliability, performance, function and system interconnection requirements (see IEC 62933 Part 2-1 § 6). For example, IEC 62933 provides for three kinds of ESS tests: (1) unit parameter tests and procedures for evaluation and characterization of ESS performance (see Part 2-1 § 6.2); (2) performance tests depending on the classification and application of the ESS (see Part 2-1 § 6.3); and (3) system implementation tests that cover the general commissioning tests (see Part 2-1 § 6.4). In addition to the tests listed above, tests related to ESS hazard mitigation measures are discussed in IEC 62933 Parts 5-1 and 5-2, as well as Part V of this report.

Where a grouping of ESS modules cannot be tested concurrently due to their scale or complexity, IEC 62933 allows for separate testing for each ESS module. IEC 62933 also provides options for tests utilizing a grid simulator in case an ESS cannot be tested directly due to its connection to the grid (see Part 2-1 § 6.1). IEC 62933 Part 2-1 Annex C provides further recommendations for back-to-back tests with or without grid interconnection.

1. Parameter Tests

Parameter tests are generally recommended in accordance with the unit parameters defined in IEC 62933 Part 2-1 § 5.2. As discussed in turn below, IEC 62933 Part 2-1 §§ 6.2.1 through 6.2.8 provide descriptions and procedures of the following parameter tests, respectively:

[11] The terms "(main) electrical parameters" and "performance parameters" are used interchangeably in Section 5.4.1 of IEC 62933 Part 3-1.

a. actual energy capacity test;
b. input and output power rating test;
c. roundtrip efficiency test;
d. expected service life test;
e. system response test;
f. auxiliary power consumption test;
g. self-discharge of ESS test; and
h. rated voltage and frequency range test.

a. Actual Energy Capacity Test

The actual energy capacity test compares the calculated actual energy capacity with the nominal energy capacity, using two different formulae depending on the typical ESS architecture (see IEC 62933 Part 2-1 §§ 5.1.4, 5.2.1, 6.2.1).

b. Input and Output Power Rating Test

The input and output power rating test, which includes an active power test, a reactive power test and an apparent power test, involves the procedures of the actual energy capacity test shown in IEC 62933 Part 2-1 § 6.2.1. The typical testing points for the apparent power test are displayed in a figure in Section 6.2.2.

c. Roundtrip Efficiency Test

IEC 62933 Part 2-1 § 6.2.3 provides that the roundtrip efficiency test should be performed following the procedures of the actual energy capacity test shown in Section 6.2.1 in line with formulae presented in Section 5.2.3. The documentation format for the roundtrip efficiency test is provided in a table within this section.

d. Expected Service Life Test

Due to the wide variety in applications and operating conditions for ESSs, IEC 62933 does not provide standardized procedures for the expected service life test (see Part 2-1 § 6.2.4). Instead, IEC 62933 Part 2-1 describes the degradation characteristic supplementing Section 5.2.4 and defines the data that the system supplier should provide in order to estimate the service life of the ESS.

e. System Response Test

The system response test comprises the measuring of step response times and ramp rates with different set points. IEC 62933 requires that the test should be repeated more than two times. Detailed procedures and illustrations for the system response test are provided in IEC 62933 Part 2-1 § 6.2.5. For ESSs with grid stabilization applications, this section of IEC 62933 suggests additional items to consider when performing the system response test.

f. Auxiliary Power Consumption Test

In the auxiliary power consumption test, the power consumption of five independent parameters (e.g., stand-by state and rated output active power) are measured and estimated. IEC 62933 shows two different directions according to the two typical ESS architectures (see Part 2-1 §§ 5.1.4 and 6.2.6).

g. Self-Discharge of ESS Test

IEC 62933 Part 2-1 § 6.2.7 provides step-by-step procedures for the self-discharge of ESS test with a requirement that the system supplier should present the environmental conditions under which the ESSs discharge at a maximum rate upon the user's request.

h. Rated Voltage and Frequency Range Test

IEC 62933 requires that the voltage, frequency and active power at the POC should be documented in four different test cases in the rated voltage and frequency range test. The four different test cases, which demonstrate the combinations of the voltage and frequency being maximum or minimum with constant rated active power input or output, as well as the specific test procedures for each testing case, are provided in Part 2-1 § 6.2.8.

2. Performance Tests

Under IEC 62933, different performance tests are required depending on the classification of ESS applications: Classes A, B and C, as discussed in Section II.A above.

IEC 62933 Part 2-1 § 6.3.2 describes two performance tests required for Class A ESSs. One of the required performance tests, the duty cycle roundtrip efficiency test, and its procedure is discussed in Part 2-1 § 6.3.2.2. Part 2-1 Annex A.2 furnishes an example of a Class A application duty cycle test. The other performance test, the fluctuation reduction test, is presented in Part 2-1 § 6.3.2.3, and its procedure is shown in Annex B.

The duty cycle roundtrip efficiency test is also required for Class B ESSs, and its test methods are provided in IEC 62933 Part 2-1 § 6.3.3.2. Part 2-1 Annex A.3 provides an example of Class B application duty cycles.

IEC 62933 requires Class C ESSs to have a black start output voltage test that evaluates the performance of the systems during a power outage. The test procedure is provided in Part 2-1 § 6.3.4.

3. System Implementation Tests

Various inspections and verification tests that can be performed upon ESS implementation are listed in IEC 62933 Part 2-1 § 6.4 and Part 3-1 § 6.

IEC 62933 Part 2-1 § 6.4.1 requires the following visual inspections to be performed as applicable before an ESS is energized:

- installation of covers for live, hot and cold parts, and adequate distance from users;
- installation of fences, walls, locking systems of doors and access panels, and notices indicating the restricted access area;
- installation of ventilation systems;
- installation of firefighting systems;
- measures for earthquakes; and
- measures for lightning.

IEC 62933 Part 2-1 § 6.4.2 requires that the continuity of conductors be visually inspected in addition to a continuity test and insulation resistance test pursuant to IEC 60364 or IEC 61936. Section 6.4.2 also requires the labels, drawings and design documents to be inspected for electrical connections. Additionally, the phase sequences of both the ESS and the grid areas are required to be confirmed on three-phase systems.

Other inspection and verification tests addressed in IEC 62933 Part 2-1 include:

- earthing test (see § 6.4.3);
- insulation test (see § 6.4.4);
- protective and switching device test (see § 6.4.5);
- equipment and basic function test (see § 6.4.6);
- grid connection compatibility test (see § 6.4.7);
- availability energy test (see § 6.4.8); and
- electromagnetic compatibility ("EMC") immunity test (see § 6.4.9).

With respect to the equipment and basic function test in Section 6.4.6, the following four sub-tests are included:

1) starting and stopping test;
2) load tripping test;
3) operating cycle test (input and output power operating test); and
4) measurement, control, and monitoring system and communication test.

The grid connection compatibility test in § 6.4.7 consists of measurement of harmonic currents and verification tests for temporary voltage drop (see also AUS/NZ 5139 § 4.3.1.2, which requires all grid connections for BESSs to meet the requirements of AS/NZS 4777.1).

For factory pre-assembled ESSs, IEC 62933 Part 3-1 § 6.1 provides general factory acceptance test ("FAT") guidelines suggesting how details of the FAT protocol should be determined and when the FAT protocol should be prepared by the system supplier for user approval.

To confirm the performance of the commissioned ESSs, a site acceptance test ("SAT") should be performed. IEC 62933 Part 3-1 § 6.3 allows for the SAT to be performed in several stages, or for the FAT to be performed instead of the SAT, depending on the size of the commissioned ESS and the installation environment, provided that the whole system is examined. All test results are required to be kept as complete records. Similar to the FAT protocol, the details of the SAT protocol should be discussed and determined between ESS suppliers and the owners.

III. PLANNING OF ENERGY STORAGE SYSTEMS

The specifications of ESSs such as functionality, accumulation subsystem, and power conversion subsystem depend on the topology of the grid, power demand, and generated power available at the POC. This requires stakeholders (e.g., planners, owners, operators, constructors, suppliers, and/or aggregators of ESSs) to define the application of the planned ESS and specify requirements of the ESS according to the application during the planning phase (see IEC 62933 Part 3-1 § 5.1).

NFPA 855 provides guidance related to the planning of ESSs with a focus on plans being made available to the relevant authorities. For example, NFPA 885 § 4.1.2.1.1 requires ESS plans and specifications including fire protection and suppression plans to be submitted to the authority having jurisdiction ("AHJ"). In the case of ESSs that are utilized as a component of a critical infrastructural electric grid, NFPA 855 similarly requires the plans and specifications to be provided to the AHJ in accordance with applicable governmental laws and regulations (see § 4.1.2.1.2).[12]

IEC 62933 contains an entire volume (i.e., Part 3-1) dedicated to the planning of ESSs and generally addresses various points of attention in ESS planning, rather than a step-by-step guide to plan an ESS. Although some specific requirements that should be met during the ESS sizing and planning phase are presented in other sections of IEC 62933 (e.g., Part 3-1 Annex A.3), the majority of the guidelines for AC grid-connected ESS planning (some parts are applicable to DC grid-connected ESSs as well) are presented in Section 5 of IEC 62933 Part 3-1. Section 5 also discusses factors that should be considered to help planners effectively collect relevant information, such as maintenance requirements and end-of-service life values from ESS suppliers. As discussed in turn below, such factors include: (A) system environment; (B) system sizing and selection; and (C) functional system performance.

A. System Environment

IEC 62933 requires that the classification of environmental conditions provided in IEC 60721-1 and installation site-specific requirements to be taken into consideration during the planning phase (see Part 3-1 § 5.2.1). Annex B of IEC 62933 Part 3-1 provides examples of site-specific requirements and risk mitigation measures related to installation sites, which are also discussed in Section V.D.1 below. In particular, as discussed in turn below, IEC 62933 Part 3-1 § 5.2 addresses three aspects for environmental considerations and related regulations when planning for an ESS installation: (1) grid parameters and requirements (see § 5.2.2); (2) service conditions (see § 5.2.3); and (3) standards and local regulations (see § 5.2.4).

1. Grid Parameters

When planning an ESS, electrical parameters and ESS connection constraints should be considered in connection with the ESS service environment (see IEC 62933 Part 3-1 § 5.2.2). The

[12] For grid-connected ESSs, IEC 62933 Part 3-1 § 5.4.1 also requires that the usage conditions of the ESS (e.g., operation patterns, environmental conditions, and maintenance cycle) be considered to maintain performance specifications throughout the service life (see Part 3-1 § 5.4.1).

electrical parameters include the grid parameters at the POC such as nominal voltage of the service and highest voltage for components (see § 5.2.2.1). The constraints include emissions and disturbances of an ESS at the POC that lead to harmonic distortion or other undesired effects (see § 5.2.2.3). As discussed in Section II.C of this report, IEC 62933 Part 2-1 discusses appropriate testing methods and procedures for the assessment of possible issues.

2. Environmental Considerations

Environmental considerations in planning ESSs involve multi-directional interactions between ESS components, micro to macro scale environmental aspects including natural or artificial surroundings, and humans. IEC 62933 Part 1 § 7 provides terms and definitions for ESS safety and environmental issues, and Part 4 §§ 3.8 through 3.11 define environment, environmental aspect, environmental impact, and environmental issues, respectively.

a. General Guidance on Environmental Issues

IEC 62933 Part 4-1 § 5 describes environmental issues related to ESSs from three general viewpoints: (1) system life cycle; (2) system aspects; and (3) storage technology independence. The system life cycle viewpoint considers environmental impacts from the product acquisition stage, into the installation and operation and maintenance stages, and through the disassembly stage. The system aspects viewpoint considers both (a) ESS impacts on the environment, and (b) environmental impacts to ESSs. The technology independence viewpoint considers both (a) issues caused independently of storage technologies, and (b) issues that are specific to particular storage technologies.

Based on the three viewpoints above, IEC 62933 Part 4-1 § 6 discusses environmental guidelines for ESS systems, including guidelines for:

1) issues posed by ESS systems to the environment (see IEC 62933 Part 4-1 § 6.2);
2) issues posed by the environment to ESS systems (see IEC 62933 Part 4-1 § 6.3), including lightning, seismic risk, water inundation, temperature, barometric pressure, wind, ice/snow, vermin, vibration, dust/smoke, fire, electromagnetic sources, humidity, salt/corrosion, solar irradiation and sediment accumulation, as well as altitude (see IEC 62933 Part 3-1 § 5.2.3); and
3) issues posed by ESSs that have a chronic impact on humans.

b. ESS Lifecycle Impacts on the Environment

Risks to the natural environment posed by BESSs are an emerging area of focus as battery systems proliferate throughout the globe. For example, on December 10, 2020, the European Commission published a new proposed regulation on batteries ("2020 Batteries Regulation") aimed to ensure that batteries placed in the EU market are sustainable and safe throughout their entire lifecycle.[13] As stated by the European Commission:

[13] See *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning batteries and waste batteries, repealing Directive 2006/66/EX and amending Regulation (EU) No 2019/1020* (European Commission, December 10, 2020) available at: https://ec.europa.eu/environment/waste/batteries/pdf/Proposal_for_a_Regulation_on_batteries_and_waste_batteries.pdf. Additional commentary from the European Commission on the 2020 Batteries Regulation is available at: https://ec.europa.eu/environment/waste/batteries/.

> The proposal's objectives are threefold: 1) strengthening the functioning of the internal market (including products, processes, waste batteries and recyclates), by ensuring a level playing field through a common set of rules; 2) promoting a circular economy; and 3) reducing environmental and social impacts throughout all stages of the battery life cycle. These three objectives are strongly interlinked.[14]

If the EU's proposed 2020 Batteries Regulation takes effect as currently scheduled for January 1, 2022, it will "replace the current [2006] Batteries Directive" which, as explained by the European Commission, "covers only the end-of-life stage of batteries through the [2006] Batteries Directive. There are currently no legal provisions in the EU that cover other aspects of the production and use phases of batteries, such as electrochemical performance and durability, GHG emissions, or responsible sourcing."[15]

c. General Protective Measures against Environmental Conditions

The various codes covered in this report (see, e.g., IEC 62933 Part 3-1 §§ 5.2.3.3, 5.2.3.4; AS/NZS 5139 § 4.2.3.1; NFPA 855 § 4.2.6; CA SED Checklist) require ESSs to be designed and constructed with consideration for potential short- and long-term effects from environmental conditions including ambient temperature, solar radiation, high humidity, dust, and corrosive atmospheres. Section 5.1.2 of IEC 62933 Part 2-1 similarly provides parameters for normal environmental conditions including ambient air temperature, solar radiation, altitude and humidity under which the ESS should be used and therefore tested, and recommends that precipitation should also be taken into account. Air temperature, humidity and precipitation may be key considerations for testing parameters in Thailand's warm and humid tropical rainforest and monsoon climates.

Appropriate protections and/or measurements should be provided in order to maintain the condition of the space where an ESS is located in accordance with manufacturer's specifications. In the case of BESSs, AS/NZS 5139 § 4.2.3.1 identifies locations where a BESS should not be installed (e.g., near localized or general heat sources and combustible materials). More detailed discussion regarding installation location is provided in Section IV.D.1 below.

i. Earthquake

The potential for impacts from seismic activity is a common consideration in the planning and design of an ESS. For example, IEC 62933 Part 3-1 § 5.2.3.2 and AS/NZS 5139 § 4.2.6 provide that ESSs and their support structures should be designed in accordance with the local codes and the seismic classification of the site. NFPA 855 (see § 4.3.3) and the NYBESSG (see page 45) similarly provide that an ESS's seismic design requirements should be in compliance with the local or international building codes. Additional considerations for earthquakes include increased seismic restraint requirements for the upper tier(s) of battery modules when multi-tier BESS stands or enclosures are used, and a need for consultation with a structural engineer when installing BESSs (see AS/NZS 5139 §§ 4.2.6 and 6.2.8).

ii. Inundation and Wind

Similar to the considerations for earthquakes, IEC 62933 Part 3-1 §§ 5.2.3.5 and 5.2.3.6

[14] 2020 Batteries Regulation at 2.
[15] Id.

recommend that ESS protective measurements against flood or wind should comply with local regulations, if applicable. If the installation site is subject to flooding or large influence by wind, IEC 62933 requires that ESSs have protective measures against flood or wind, regardless of the absence of local regulations. The New York Model Permit (see NYBESSG at 20) further requires the preparation of an ESS elevation drawing with respect to flood plains and provides that the ESS should be above base flood elevation. In the case of BESSs, AS/NZS 5139 § 4.2.3.2 recommends the use of an ingress protection (IP) code rating as specified in IEC 60529 for protection against flood or ingress of foreign objects, and provides additional guidelines for minimum protection ratings.

3. Standards and Local Regulations

IEC 62933 Part 3-1 § 5.2 generally recommends that where any environmental issues are present or expected, mitigation measures be implemented according to product standards, technology-specific standards, and/or relevant local regulations. IEC 62933 also requires all standards and local regulations that affect the ESS design to be explored in the planning phase and suggests that environmental impacts and issues that an ESS can cause should be taken into account from two perspectives: (1) regular occurrence (e.g., noise, exhaust gas, and EMC); and (2) irregular occurrence (e.g., fire, explosion, collapse, and disposal) (see IEC 62933 Part 3-1 §§ 5.2.4.1 and 5.5.4.2). Annex B of IEC 62933 Part 3-2 provides examples of site-specific environmental considerations with regard to ESS installation. IEC 62933 Part 3-1 §§ 5.2.1, 5.2.3.1 and 5.2.4.2 also include references to other IEC standards for more detailed discussions on the classification of environmental conditions, environmental impacts, safety measurements, and electromagnetic emissions.

B. System Sizing and Selection

Appropriate system sizing and selection are factors that can impact the safe and cost-effective implementation of an ESS.

1. Sizing

The general approach in IEC 62933 for ESS sizing involves identifying duty cycles, recovery times, and service life (see Part 3-1 § 5.3). In addition, NFPA 855 § 4.8 provides restrictions on maximum stored energy depending on the type of battery and ESS installation location.

To identify sizing requirements at the primary POC of an ESS over its whole service life, IEC 62933 Part 3-1 § 5.3 requires that duty cycles and recovery times to be specified (see § 5.4.8), and operational features to be identified with these parameters. The parameters and characteristic values to specify duty cycle (e.g., response time and expected frequency) and recovery times (e.g., minimum and maximum duration) are provided in § 5.3.1. Annex A of IEC 62933 Part 3-1 provides examples of duty cycles. It is recommended that possible future changes in grid structure and future developments in terms of power generation and consumption be considered when specifying the duty cycles and recovery times (see § 5.3.1). If an ESS has multiple operational features, superposition of duty cycles and recovery cycles for different operational features may be necessary (see § 5.3.2).

With some exceptions, NFPA 855 § 4.8 provides maximum stored energy as per battery types such as lead-acid, nickel, lithium-ion, and flow batteries utilized in BESSs. Installation location of a BESS such as non-dedicated-use buildings, outdoor locations near exposures, open parking garages and rooftops of buildings, and the use of mobile ESS equipment also affect the maximum stored energy provided by NFPA 855. Additional discussion regarding the suitability of ESS locations is provided in Section V.D.1 below.

2. Selection

With regard to BESS selection, AS/NZS 5139 § 2.2.3 lists the following items as points of attention:

- compatible PCE;
- functional parameters;
- service life;
- installation location and its environmental facts;
- maximum acceptable nominal system voltage;
- additional hazard issues; and
- service provisions and ability to replace components.

With respect to the selection of certain specific types of battery systems such as lead acid batteries, nickel cadmium batteries, and secondary lithium cells and batteries, AS/NZS 5139 § 6.1 provides different standards to be followed. Also, operation parameters and controls of BESSs or other battery systems are required to be configured in accordance with manufacturers' requirements (see AS/NZS 5139 §§ 5.1 and 6.1).

C. Functional System Performance

As discussed above, IEC 62933 Part 3-1 § 5 provides various applications and necessary functions of ESSs to help planners define the specifications of an ESS and design a system smoothly. As discussed in turn below, Section 5.5 of IEC 62933 Part 3-1 provides: (1) different options to configure a control system of an ESS by presenting typical applications of Class A, Class B, and Class C ESSs (discussed in Section II.A above); (2) grid connected ESS functionalities, requirements and considerations for planning them; and (3) recommendations for the communication interface of ESSs.

1. Characteristics of Grid-Connected ESSs

Sections 5.5.1.3 through 5.5.1.5 of IEC 62933 Part 3-1 identify requirements and points of attention regarding grid connected ESSs such as supply reliability (see § 5.5.1.3), grid stability (see § 5.5.1.4), and fault current (see § 5.5.1.5). In particular, IEC 62933 requires ESSs to comply with grid codes and local connection rules for grid stability. In addition, IEC 62933 identifies certain parameters that ESS suppliers should provide to system operators according to requirements of network operators (see § 5.5.1.4).

IEC 62933 Part 3-1 § 5.5.2 explains and illustrates possible operational states that ESS control systems can adopt. Where an ESS is connected to the grid, the ESS may have different kinds of activated controls. Stakeholders should specify the operational modes required per applications.

IEC 62933 Part 3-1 § 5.5.3 introduces as part of the system control program a specific grid frequency support mode that can be included as a requirement in local grid codes. Grid frequency deviation from a pre-set value places an ESS in this mode, wherein the ESS can support grid frequency by supplying its active power. Section 5.5.3 also provides two parameters to be set by the user (i.e., the percentage of rated active power reserved for frequency support and the frequency support strategy), a diagram representation of an automatic grid support strategy, and considerations to avoid disconnection from the activation of frequency protection modes. It should be noted that although Section 5.5.3 requires an ESS to be capable of providing a programmable droop response with activation of the grid frequency control mode, it does not preclude the implementation of other frequency support functions, such as synthetic inertial response.

IEC 62933 Part 3-1 §§ 5.5.4 and 5.5.5 discuss two ESS system modes: (1) an islanding control mode; and (2) an active power limitation mode, respectively. Using graphs and charts that illustrate particular case examples, Sections 5.5.6 through 5.5.8 explain ESS power controlling functions (e.g., manual active power control and automatic load following control). Four power control modes for grid voltage support: (1) constant value control modes; (2) voltage-related control modes; (3) active power-related control modes; and (4) voltage-related active power reduction, are presented in detail in Section 5.5.9.

2. Communication Interface

Section 5.6 of IEC 62933 Part 3-1 presents recommendations for the communication interface of ESSs, discussing the importance of information models (see § 5.6.2) and remote monitoring and controls (see § 5.6.3), including cybersecurity (see § 5.6.3.2). NFPA 855 § 5.4 also requires communication interface between ESS components and site-located systems for safe operation of the ESS (see also AS/NZS 5139 § 4.4.3.1).

IEC 62933 Part 3-1 § 5.6.2 describes and illustrates how information models are fundamental to achieving interoperability and may allow aggregation of multiple ESSs that are connected to the same POC. Three general benefits of having information modelling and seven categories of information necessary to achieve information modelling are also presented.

To help identify monitoring activity requirements for a planned ESS, IEC 62933 Part 3-1 § 5.6.3.1 provides three monitoring categories of ESSs based on the level of relevance and the impact the planned ESS can have to or on the connected network. A table is provided to guide the defining processes of the types of information exchanged (ESS characteristics, status, measurements, operating limits, forecast, disconnection, and diagnostics) and the three monitoring categories. Examples of each type of information that could be exchanged are shown in detail in a table in Section 5.6.3.4. The ESS application and capacity, voltage level of the connection, and the criticalities of the local power system are the defining factors of the information to be shared and exchanged. IEC 62933 recommends that the information profile should be defined in the planning phase and be flexible to support future integrations (see § 5.6.3.4).[16]

A definition of interoperability and required items to configure such synchronizing capabilities among ESSs and stakeholders are provided in Section 5.6.3.2 of IEC 62933 Part 3-1. One of the required items for interoperability, standard protocols, is discussed in § 5.6.3.3, which provides several common standards for grid management involving control centers.

[16] IEEE 1547-2018 also provides some insight into the technical information that should be available at the communications interface.

IV. PERFORMANCE ASSESSMENTS

The standards referenced in this report have varying requirements and guidelines regarding the installation and commissioning of ESSs. Those requirements and guidelines generally relate to validation of the conditions and specifications of an ESS related to the system environment, the main electrical system parameters, the functional system performance, and the communication interface (see IEC 62933 Part 3-1 § 6.2.1). In line with the organization of IEC 62933 Part 3-1 § 6, the following sections of this report address the following phases of an ESS implementation: (A) installation; (B) commissioning; and (C) performance monitoring.

A. Installation Phase

IEC 62933 Part 3-1 § 6.2.1 separates the installation phase into two stages: (1) a transportation stage; and (2) a site-assembling stage, and provides a table of electrical, chemical, and mechanical items to be considered. Annex B of IEC 62933 Part 3-1 provides examples of considerations at the transportation and on-site storage stages and site-assembling stage, as well as considerations for hazard prevention and protection measures.

Other standards discussed in this report also provide requirements for electrical interconnections and reference codes and standards to be followed during the installation phase (see, e.g., AS/NZS 5139 § 4.2.1; NYBESSG at 28; 2015 IRC § R327.6 in NYBESSG at 35; and NFPA 855 §§ 4.3.1 and 5.1).[17] In addition, NFPA 855 provides exceptions to the requirements for lead-acid and nickel-cadmium battery systems that are in use under specific conditions (see §§ 5.1.1 and 5.1.2) and system interconnection guidelines for nonelectrical systems such as natural gas, liquefied petroleum gas systems and storage, hydrogen fuel systems and storage, biogas, liquid fuels, and water (see § 5.3). IRC § R327.6 (see NYBESSG at 35) and Section 4.2.8 of NFPA 855 add that inverters and converters should be listed and labeled in accordance with UL 1741 or UL 9540.[18]

The New York Model Law and Permit (see NYBESSG at 9, 20) and the CA SED Checklist provide relatively specific guidelines for ESS installation. The New York Model Law addresses general rules around utility line placement, and the New York Model Permit requires the following items to be provided:

- Diagrams for:
  - grounding and bonding for the installed BESS;
  - interconnection, disconnection, and overcurrent protection methods;
  - detailed wiring information for new circuits; and
  - ratings for new and existing service equipment; and
- Specifications and installation instructions for equipment such as batteries, inverters, transformers, and HVAC/thermal management systems.

The New York Model Permit also requires that installation processes comply with the BESS

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[17] AS/NZS 5139 § 4.2.1 requires compliance with AS/NZS 3000 for the AC electrical interconnection and AZ/NZS 4777.1 for a grid-connected BESS installation. In New York, NEC Article 705.12 should be followed for the interconnection methods (see NYBESSG at 28). 2015 IRC § R327.6 in NYBESSG at 35 lists NFPA 70 for system installation reference, and UL 1741 or UL 9540 for inverter listing and labeling reference. NFPA 855 § 5.1 requires compliance with NFPA 70 or IEEE C2 for electrical installation.

[18] A new supplement to UL 1741 that was published in 2020 (i.e., UL 1741SB) directly refers to IEEE 1547.1-2020 test procedures.

Electrical Checklist. Similar to the New York Electrical Checklist, the CA SED Checklist provides guidelines for inspections identifying specific items for verification (e.g., inspection of inverters for hotspots, mechanical, and/or structural defects; inspection of ESS certifications; and battery module and cable security).

B. Commissioning Phase

Suppliers, commissioning agents, and/or owners of ESSs are generally required to evaluate the installed ESS's compliance with reported performance capacities and specifications while ESS commissioning is conducted in accordance with manufacturer's commissioning requirements or as planned by the stakeholders (see, e.g., NFPA 855 §§ 4.1.2.4, 6.1.1; AS/NZS 5139 § 4.4.3.1; NFPA 885 § 6.1.2). In New York, a commissioning plan is required to be approved prior to initiating commissioning (see 2015 IFC § 608.9.1 in NYBESSG at 43). IEC 62933 Part 3-1 § 6.2.3 provides a tabular listing of performance test items, as well as general guidelines for verifying various items of the installed ESS such as insulation resistance (see § 6.2.3.2.1) and dielectric strength (see § 6.2.3.2.2) during the commissioning phase. It also calls for paying particular attention to the system's physical and cyber security, and safety, during the planning and commissioning phase, and provides reference standards such as IEC 62351, IEC 62443, and ISO/SEC 27000 (see § 6.2.3.1).

With regard to commissioning of BESSs, AS/NZS 5139 provides additional requirements involving testing for system shutdown procedures and DC connections if applicable (see § 4.4.3). AS/NZS 5139 § 6.4.3.2 also specifies content for an introduction or orientation for the system owner.

In addition to the general requirements during the commissioning phase, NFPA 855 §§ 6.1.3 through 6.1.5 and 6.4, and 2015 IFC § 608.9.1 (see NYBESSG at 43), discuss documentation of the commissioning plan, processes, and results and submission of the report to the AHJ, as well as requirements for a decommissioning plan and recommissioning of ESSs. For lead-acid and nickel-cadmium battery systems, NFPA 855 § 6.1 permits a commissioning plan in accordance with recognized industry practices or applicable governmental laws and regulations depending on the conditions of the batteries, while 2015 IFC § 608.9.1 does not require commissioning for these battery systems.

C. Performance Monitoring Phase

To properly monitor performance degradation in ESS functions and evaluate aging capabilities of the ESS, IEC 62933 requires the performance parameters of the ESS to be measured periodically. Providing various points of attention for ESS performance monitoring in a table, IEC 62933 recommends that the testing procedures shown in IEC 62933 Part 2-1 or methods and procedures agreed on between system suppliers and users should be utilized. A table detailing suggestions regarding frequencies and measuring durations of monitoring items is presented in Part 3-1 § 6.4.

While IEC 62933 § 6.4 recommends the use of energy metering devices at the auxiliary and primary POC, 2015 IFC § 608.9.2.1 (see NYBESSG at 44) requires inspections and evaluations of ESS monitoring and protecting systems. The CA SED Checklist also requires monthly in-service inspections and maintenance of ESSs. The monthly inspection guideline provided in the CA SED Checklist mainly includes safety inspections rather than ESS function and performance monitoring instructions. The monitoring of ESSs as a safety and hazard mitigation measure is further discussed in Part V below.

V. ESS SAFETY CONSIDERATIONS

The case studies referenced in the NREL Report (e.g., the Arizona case study) highlighted the inherent dangers posed by ESSs, and the need for codes, standards and procedures to support their safe and reliable deployment. Despite recent efforts to enable safe ESS operation, safety considerations continue to be a key area of focus of ESS-related standards. Parts 5-1 and 5-2 of IEC 62933, respectively, address safety considerations and requirements for ESSs in general and BESSs in particular. Substantial portions of those volumes are duplicative. In order to reduce the degree of duplication, this Part V of this report addresses ESS and BESS safety together, with general references to ESSs and specific references to BESSs from other codes, as appropriate.

A. General Guidelines for ESS Safety

The general approach in IEC 62933 for addressing ESS hazards includes three steps: (1) identification of system hazards; (2) risk analysis of system hazards; and (3) measures to reduce risks (see IEC 62933 Part 5-1 § 4). IEC 62933 Part 5-2 §§ 4.1 and 4.2 list factors that may impact the level of risk associated with BESSs, including POC, energy capacity, site occupancy, chemistry and application (i.e., residential, commercial, industrial, and utility).

As it relates to system capacity, AS/NZS 5139 includes specific guidance to address a situation where an installation includes multiple individual BESSs that comprise a larger BESS with an aggregate energy capacity greater than 200 kWh (see AS/NZS 5139 § 2.3.2).

With regard to system chemistry, AS/NZS 5139 § 2.2.2 includes restrictions and requirements regarding the use of multiple technologies, chemistries or systems, and their connections within a single BESS. For example, different chemistries pose different types of hazards and limitations to be mitigated in different fashion. With regard to system connections, the New York Model Law prohibits direct physical contact between electrochemically dissimilar metals to prevent corrosion (see NYBESSG at 26).

Similarly, the New York Model Law has separate sets of requirements for “Tier 1” BESSs (i.e., systems with aggregate energy capacity of 600 kWh or less and, if within an enclosed area, a system containing only a single BESS technology) versus “Tier 2” BESSs (i.e., systems with energy capacity greater than 600 kWh or comprised of more than one technology in an enclosed area. As a result of their greater size and/or complexity, Tier 2 systems under the New York Model Law are subject to considerably more stringent permitting requirements (see NYBESSG at 9-12).

Given the diversity of loads in Thailand, consideration should be given to having different requirements for systems with different sizes and applications.

1. Changes in Ownership, Control or Use

Changes in the ownership, control or use of an ESS may require clarification on the roles and responsibilities for managing hazards associated with the system. Where such changes occur, IEC 62933 Part 5-2 § 4.3 requires that system manuals and documentation be passed to the new owner or operator. Additional requirements regarding BESS ownership changes are included in the New York Model Law, which requires that the new owner or operator inform the appropriate authorities in writing within the required timeframe and provides that failure to furnish such notification will render the related permits and local approvals void (see NYBESSG at 12). It should be noted, however, that the requirements of NFPA 855 generally do not apply retroactively; therefore, in the absence of a situation that presents an unacceptable degree of risk, mere changes in ownership generally should not give rise to additional permitting requirements (see NFPA 855 § 1.4; NYBESSG at 9).

B. Hazard Considerations

The hazards associated with ESSs generally include electrical, energy, mechanical, electric/magnetic/electromagnetic fields, fire, temperature, explosive gas, chemical and toxic fume hazards. IEC 62933 Part 5-1 § 5 provides general discussion of how these types of hazards can arise and cause harm to the human body, such as electric shock, burns, mechanical trauma, skin irritation and poisoning. More detailed discussion regarding protections against ESS-related hazards is provided in Section V.D.4 below. In addition, IEC 62933 Part 5-1 § 5.6 discusses unsuitable working conditions and factors that can increase the risk of injury to workers, such as heavy lifting, repetitious tasks, awkward postures, cold temperatures, excessive noise leading to hearing loss, and excessive radio frequency exposure.

C. Risk Assessment

Risk assessments are a common feature in codes related to ESS safety, under which the foreseeable hazards associated with a particular ESS should be identified prior to planning and installing the system (see, e.g., AS/NZS 5139 § 4.2.1). NFPA 855 § 4.1.4 (see also NYBESSG at 41-42) sets forth specific requirements for ESS "Hazard Mitigation Analysis" including: situations requiring review and approval by relevant authorities (see NFPA 855 § 4.1.4.1); a list of the failure situations that are required to be analyzed (see NFPA 855 § 4.1.4.2); criteria for approval (see NFPA 855 § 4.1.4.3); documentation (see NFPA 855 § 4.1.4.4); and installation, testing and maintenance of required hazard mitigation systems and equipment (see NFPA 855 § 4.1.4.5).

Under IEC 62933, the process for assessing risks related to ESS systems begins with an assessment of the general characteristics of the system itself (see Part 5-1 § 6.1.1). Specific characteristics related to the type of storage technology are also taken into account (see Part 5-1 § 6.2.2). Annex A of Part 5-1 describes the general risks associated with different mechanical, electrochemical and chemical storage technologies. In the case of a BESS, Part 5-2 § 6.1.1 further provides for the creation of a storage model showing the BESS architecture and components within subsystems. To assist this process, Part 5-2 § 6.1.2 provides a listing of different types of BESS auxiliary subsystems.

The next step of a risk assessment under IEC 62933 considers the conditions under which the energy is to be stored, including types of grids (see Part 5-1 § 6.2.1) and types of system applications (see Part 5-1 § 6.2.2). The location (see Part 5-1 § 6.2.3) and vulnerable elements affecting the system (see Part 5-1 § 6.2.4) are also taken into account. IEC 62933 Part 5-1 §§ 6.2.5 and 6.2.6 provide recommendations for situations where systems are exposed to the untrained public and other sources of external threats. Additional considerations regarding storage conditions include unattended operation (see Part 5-1 § 6.2.7) and unintentional islanding (see Part 5-1 § 6.2.8). In the case of a BESS, Annex B of Part 5-2 provides information on BESS-specific hazards and risks.

The final step of a risk assessment under IEC 62933 is the risk analysis itself, in which the impact of the potential hazards is considered for all stages of the system's service life. General guidelines for carrying out the risk analysis are provided in Part 5-1 § 6.3.1. A listing and discussion of more specific ESS risk considerations is provided in Part 5-1 § 6.3.2, including:

- access control (see § 6.3.2.1);
- protection coordination (see § 6.3.2.2);
- malfunction detection (see § 6.3.2.3);
- system control malfunction (see § 6.3.2.4);
- auxiliary subsystem malfunction (see § 6.3.2.5);
- safety policies (see § 6.3.2.6);
- working environment, conditions and equipment (see Part 5-1 § 6.3.2.7);
- fire suppression and evacuation (see § 6.3.2.8);
- major hazards (see § 6.3.2.9; see also Section V.D.4 below); and
- maintenance risks (see § 6.3.2.10).

In the case of a BESS, IEC 62933 Part 5-2 § 6.3.2 requires that the risk assessment include specific subsystem failure modes as starting points for the analysis. Examples of risk scenarios for interactions between BESS subsystems are provided in Part 5-2 § 6.3.3.

Following evaluation of the various specific risk considerations, a risk analysis can be performed at the system level – e.g., failure mode and effects analysis ("FMEA"), failure modes, effects and criticality analysis ("FMECA"), probabilistic risk analysis ("PRA"), fault tree analysis ("FTA"), and hazard operational process ("HAZOP") (see IEC 62933 Part 5-1 § 6.3.3, Part 5-2 § 6.3.4). In the case of a BESS, IEC 62933 Part 5-2 § 6.4 requires appropriate mitigation measures to be taken where risks to operators, users or neighbors are deemed to be unacceptable.

D. Risk Mitigation Measures

The general approach to reducing risks under IEC 62933 is to implement risk mitigation measures where the risk assessment identifies scenarios for which the likelihood and/or severity of the consequences are not tolerable. Preventive measures should be designed to avoid or minimize the impacts or hazards, utilizing a layered approach to help prevent minor incidents from escalating into major and potentially catastrophic events (see Part 5-1 § 7.1).

In the case of BESSs, IEC 62933 Part 5-2 § 7.1 describes three general risk reduction approaches and prioritizes them in the following order: (1) inherently safe design; (2) guards and protective devices; and (3) information for end users. Part 5-2 § 7.11.1 provides further requirements for guards and protective measures to be implemented in connection with BESSs, including access control to prevent contact with untrained persons, as well as monitoring and reporting of safety parameters within electrochemical accumulation subsystems by battery management systems. Part 5-2 § 8.2.10 provides validation and testing requirements for BESS safety features related to such hazards.

In addition, AS/NZS 5139 § 4.2.1 includes general requirements that BESSs be installed by competent persons in accordance with manufacturers' instructions. Equipment that is damaged in any way may not be installed.

For both ESSs in general and BESSs in particular, IEC 62933 breaks down preventive measures in terms of the people they are designed to protect – namely neighboring inhabitants (see Part 5-1 § 7.2, Part 5-2 § 7.2) and workers and residents (see Part 5-1 § 7.3, Part 5-2 § 7.3). In either case, preventive measures are heavily dependent on location. Therefore, as discussed below, location and enclosure requirements and recommendations are prevalent in many of the codes that address ESS safety.

1. Location

IEC 62933 generally allows for ESSs to be installed in a variety of indoor, outdoor and underground locations, including residential, commercial, public access, industrial and utility locations (see Part 5-1 § 6.2.3). Some examples of suitable locations for BESSs include garages, storage rooms, dedicated BESS rooms and verandas (see, e.g., AUS/NZ 5139 § 4.2.2.1).

a. Suitable Locations

Factors affecting the suitability of an ESS location may include people in the area, system components, properties and structures, and other external influences (see IEC 62933 Part 5.1 § 6.2.4; AUS/NZ 5139 § 4.2.2). With respect to impacts on people in the area, the New York Model Law includes restrictions on noise as measured at the outside wall of any nonparticipating residence or occupied community building (see NYBESSG at 10).

The natural environment in particular poses a variety of risks that should be taken into account when considering the location of ESSs, including extreme weather conditions (e.g., ambient temperature and humidity, frost, wind, snow, fog), landslides, earthquakes, lightning and flooding (see IEC 62933 Part 5.1 § 6.2.6; AUS/NZ 5139 § 4.2.2.1; CA SED Checklist). Such factors should be determined and evaluated in connection with the risk assessment of the ESS (see AUS/NZ 5139 § 4.2.2.1). Additional discussion of environmental considerations for ESS locations is provided in Section III.A.2 above.

In the case of BESSs, IEC 62933 Part 5-2 § 7.10.9 specifically requires systems to be designed to prevent hazardous conditions arising from moisture ingress and exposure to marine environments (e.g., salt fog), as well as testing to ensure compliance with those requirements. IEC 62933 Part 5-2 § 8.2.9 provides validation and testing requirements for BESS safety features related to such hazards. Hazards related to moisture and salt air appear particularly applicable to Thailand's tropical rainforest and monsoon climates.

b. Prohibited Locations

Subject to certain exceptions, NFPA 855 generally prohibits the installation of ESSs in sleeping rooms or living areas of dwellings (see § 4.4.2.3). AS/NZS 5139 §§ 4.2.2.2 and 6.2.2.2 similarly prohibit BESS installations in the habitable rooms of a dwelling and provide further restrictions/distances on BESS locations in relation to exits, windows, ventilation, appliances, ceiling spaces, wall cavities, roofs, stairways, walkways, evacuation/escape routes and hazardous areas. NFPA 855 also includes general prohibitions on the installation of ESSs in below-grade installations (see NFPA 855 § 4.3.9.1; c.f., NYBESSB at 47), in hazardous atmospheres (see NFPA § 4.4.3.9), and on higher floors of buildings that cannot be accessed by external fire department laddering capabilities (see NFPA 855 § 4.3.9; c.f., NYBESSG at 47). Such considerations may be particularly applicable in urban areas of Thailand, such as Bangkok, where the population is in excess of 5 million and high-rise buildings are prevalent.

c. Permitting and Approvals

To facilitate the permitting of BESS installations, the New York Model Permit (see NYBESSG at 20) requires the preparation of a site plan that shows:

- the location of the structure and the location where the system is to be installed;
- conduit/cable routing of the BESS;
- underground trench detail, if applicable;
- overhead runs, if applicable;
- method and location of required ventilation equipment (if required) for indoor installations;
- method of protection from physical damage to the system;
- means of access to the system; and
- whether conductors are routed indoors or outdoors.

In addition, the New York Electrical Checklist requires verification that batteries attached to walls or floors are installed per approved plans. Where the construction deviates from approved plans, revisions to the plans are required prior to inspection (see NYBESSG at 26).

As noted in Part I above, New York's Model Law allows for flexibility in applying its requirements to local municipalities. It specifically recommends that:

> Municipalities should review this Model Law, examine their local laws and regulations and the types, size range and number of battery energy storage system projects proposed, and adopt a local law addressing the aspects of battery energy storage system development that make the most sense for each municipality, deleting, modifying, or adding other provisions as appropriate.

A similar approach may be suitable for Thailand, where municipalities vary greatly in terms of size, population density, climate, socio-economic conditions and energy resources.

Recent changes to the IFC, IRC and IBC include detailed requirements for indoor and outdoor ESS installations, many of which have been adopted in NFPA 855 and the NYBESSG. The remainder of this Section on ESS locations is structured around those new requirements.

d. Indoor Installations

Section 4.3 of NFPA 855 includes separate requirements for indoor installations in: (1) "Dedicated-Use Buildings" (i.e., buildings built primarily for the storage of BESS equipment); (2) "Non-Dedicated-Use Buildings"; and (3) "Dwelling Units and Sleeping Units".

One of the key considerations for indoor BESS installations relates to sufficient clearances for safe egress (see IEC 62933 Part 5-1 § 7.3.3.6.3; NFPA 855 § 4.3.10). In this regard, AUS/NZ 5139 § 4.2.2.1 includes specific clearance requirements for BESSs and associated equipment in corridors, hallways and lobbies. Of note, under NFPA 855, if an outdoor walk-in enclosure exceeds the maximum allowable enclosure size, it will also be subject to the requirements for indoor installations as well (see NFPA 855 § 4.4.3.2; NYBESSG at 48).

i. Dedicated-Use Buildings

Under NFPA 855, Dedicated-Use Buildings are required to comply with local building codes, may only be used for energy storage, energy generation or other electrical grid operations, and may only be occupied by personnel working on those electrical systems. To a limited degree, administrative and support personnel may also occupy a Dedicated-Use Building, provided that certain safety requirements are met – e.g., the BESS should be housed in a lockable noncombustible cabinet that includes appropriate signage (see NFPA 855 § 4.4.2.1; NYBESSG at 46, 50).

ii. Non-Dedicated-Use Buildings

Section 4.4.2.2 of NFPA 855 defines Non-Dedicated-Use Buildings as buildings that contain BESSs but are not Dedicated-Use Buildings, including dwellings and townhouses. Chapter 15 of NFPA 855 includes detailed requirements for ESS installations in one- and two-family dwellings and townhouses, including requirements for equipment listings, installation, commissioning, ESS spacing, locations, energy ratings, fire detection, protection from vehicle damage, exhaust ventilation, toxic and highly toxic gas, and electric vehicles. Of note, NFPA 855:

- generally requires that ESSs be spaced at a minimum of three feet apart (see § 15.5);
- provides that ESSs for dwellings and townhouses may only be installed in garages, on exterior walls or on the ground at a minimum of three feet from doors and windows, or in enclosed utility closets and storage or utility spaces (see § 15.6); and
- caps the maximum stored energy of a single ESS unit in dwellings and townhouses at 20 kWh, while specifying caps for aggregated ratings depending on the location and installation of the particular system (see § 15.7). See also NYBESSG at 34, 46.

The IRC also includes a general prohibition on the use of ESSs listed solely for utility or commercial use in residential applications (see NYBESSG at 34).

e. Outdoor Installations

Outdoor installations are covered under Section 4.4.3 of NFPA 855 and classified as either: (1) "remote locations" (i.e., more than 100 feet away from buildings and other hazards not associated with electrical grid infrastructure); or (2) "locations near exposures" (see also NYBESSG at 51). Pursuant to NFPA 855 § 4.4.3.3, subject to certain exceptions, ESSs located outdoors are required to be separated by a minimum ten feet from lot lines, public ways, buildings, stored combustible materials, hazardous materials, high-piled storage, and other exposure hazards (see also NYBESSG at 52). NFPA 855 also includes requirements for the location and direction of ESS exhaust outlets in relation to openings into buildings and facilities, means of egress, walkways, or pedestrian or vehicle paths (see §§ 4.4.3.3.6 and 4.4.3.3.7).

As discussed in turn below, in addition to the general requirements above, NFPA 855 includes detailed lists of specific requirements for: (1) exterior wall installations; (2) rooftop installations; (3) open parking garage installations; and (4) mobile ESS equipment.

i. Exterior Wall Installations

Section 4.4.3.10 of NFPA 855 provides specific requirements for exterior wall installations, including maximum stored energy and separation from other units, doors, windows and other openings (see also NYBESSG at 53).

ii. Rooftop and Open Garage Installations

NFPA 855 §§ 4.4.4.2 and 4.4.4.3 include specific clearance and fire suppression control requirements for rooftop and open parking garage installations (see also NYBESSG at 53-54).

Rooftop Installations

Additional requirements specific to rooftop installations are provided in NFPA 855 § 4.4.4.4, which covers items including but not limited to stairway access, service walkways, system location, roofing materials, and fire detection (see also NYBESSG at 54).

Open Parking Garages

Additional requirements specific to open parking garage installations are provided in NFPA 855 § 4.4.4.5, which covers items including but not limited to location, means of egress, fire detection, and barriers for protection from the general public (see also NYBESSG at 54).

The potential for damage caused by motor vehicles is a common consideration when assessing risks from external influences for ESSs (see IEC 62933 Part 5.1 § 6.2.6; NYBESSG at 35, 36, 45; AUS/NZ 5139 § 4.2.2.1.). In this regard, NFPA 855 § 4.3.7 provides substantial guidance on protection from vehicular impact, including detailed specifications for the installation of vehicle guard posts (see § 4.3.7.3).

Mobile ESS Equipment

Although NFPA 855 is titled "Standard for the Installation of *Stationary* Energy Storage Systems," Section 4.5 of that code also includes detailed requirements for *mobile* ESSs and operations, where mobile ESSs are charged and stored before and after deployment. The provisions included therein include requirements related to deployment, documentation, approved locations, charging and storage, mobile operations, deployment duration, restricted locations, clearances, electrical connections, local staging, fencing, size and separation, and occupied work centers (see also NYBESSG at 55).

2. Rooms and Enclosures

Pre-assembled BESSs often include enclosures that are designed, assembled and provided by the manufacturer. Where this is not the case – or where additional enclosure or housing is required to provide greater protection due to environmental, location, ventilation or other issues (see AS NZS 5139 § 4.2.1) – a dedicated room or enclosure may need to be designed to house the system. In general, ESS rooms and enclosures should be designed, laid out and constructed with an eye toward protecting the ESS from external influences, and protecting against harm to workers, residents and neighboring inhabitants.

In addition to the requirements for indoor and outdoor ESS locations discussed above, AZ/NZS 5139 and other code provisions furnish additional guidance and requirements for the design, layout and construction of BESS enclosures and rooms. Some of the common requirements for BESS enclosures and rooms include:

- dedicated use (i.e., the enclosure/room may only be used for the BESS and related equipment; equipment not related to the BESS must be stored elsewhere) (see AS/NZS 5139 § 6.2.6.1);
- site access (e.g., access roads, snow removal, vegetation control) at a level acceptable to emergency responders (see NFPA 855 §§ 4.4.3.6, 4.4.3.8; NYBESSG at 9, 13, 48);
- weatherproof construction in accordance with local building codes (see NFPA 855 §§ 4.3.6, 4.4.3.7.1; NYBESSG at 13) and resistance against other external factors, including insects and vermin (see AS/NZS 5139 § 6.2.6.1);
- noncombustible construction (see NFPA 855 §§ 4.4.3.7.2, 7.10.5; NYBESSG at 44);

- separate compartments with fireproof partitions and access for (1) the battery system, (2) the PCE, and (3) circuit breakers and discharge circuits (see NFPA 855 § 7.10.5; AZ/NZS 5139 § 6.2.5.3);
- protection against ESS-related hazards (as further discussed in Section V.D.4 below);
- suitability for the type of battery system being installed (e.g., sufficient ventilation for operation within recommended temperature ranges) (see AS/NZS 5139 § 6.2.6.1) and selected wiring methods (see NYBESSG at 26);
- maximum allowable quantities of BESS storage (see NYBESSG at 40, 47);
- suitable working environments, including sufficient size, adequate and safely located task lighting, prevention of hazardous emissions and leaks, and local safety controls that cannot be overridden by remote/automatic controls, as well as access to and working space clearances for operation, inspection, troubleshooting, maintenance, removal and replacement (see IEC 62933 Part 5-1 § 7.3.3.6; NFPA 855 § 4.3.2; NYBESSG at 10, 13, 26, 45; AS/NZS 5139 §§ 4.2.2.1, 6.2.5.2; 6.2.6.1, 6.2.6.2, 6.2.6.3; CA SED Checklist);
- fire-rated barriers/assemblies (e.g., two-hour fire resistance rating) between rooms/areas containing ESSs and other areas/rooms in the installation (see NFPA 855 § 4.3.6; NYBESSG at 26, 51; AS/NZS 5139 § 4.2.4.2);
- adequate means of egress separation under fire conditions (e.g., separation from fire exits in neighboring buildings; outward opening doors) (see NFPA 855 § 4.4.3.4; NYBESSG at 26, 48; AS/NZS 5139 § 6.2.6.1); and
- security against unauthorized entry (e.g., by requiring the use of a key or tool for access) (see NFPA 855 § 4.3.8; AS/NZS 5139 §§ 6.2.5.2.1, 6.2.6.1) and periodic inspections to observe any signs of break-in, intrusion or vandalism (see CA SED Checklist). Where a dedicated BESS room is only accessible to authorized personnel, NFPA 855 § 4.3.11 permits the BESS to be installed on an open rack; provided that walk-in units should only be entered for purposes of inspection, maintenance and repair of BESS units and ancillary equipment, and may not be occupied for other purposes (see NYBESSG at 46).

Where an adequate BESS room or enclosure is not provided by the manufacturer, AS/NZS 5139 §§ 6.2.2.1 and 6.2.2.2 provide additional detailed guidance on requirements for the design, layout and construction of battery system enclosures and rooms. AS/NZS 5139 describes a dedicated battery system "enclosure" as an enclosed area that is not sufficiently large to allow a person to stand and move around inside. In contrast, a battery system "room" is described as a dedicated room that houses a battery system and its related components and is accessible via a door large enough for a person to enter and walk within. In addition to the general requirements above, AS/NZS 5139 §§ 6.2.2.1 and 6.2.2.2 include requirements and helpful illustrations for minimum unimpeded access on the working side of battery systems in enclosures and rooms (respectively), as well as additional requirements related to:

- installation of metallic equipment;
- minimum aisle width;
- spacing between battery cells, containers or modules;
- clearances between battery cells, containers or modules, in relation to walls or structures;
- tiered, vertically mounted cells, batteries and modules;
- racked, horizontally mounted cells, batteries and modules;
- maximum height of components above floor level; and
- proximity of auxiliary equipment to doors and access panels.

3. Safe System Design

IEC 62933 Part 5-1 § 7.8 provides a high-level discussion of factors that may affect the safe operation of ESSs over their service lives (see IEC 62933 Part 5-1 § 7.8.1), including the initial safety design (see IEC 62933 Part 5-1 § 7.8.2), and the need for subsequent safety design review as new information becomes available in the future or in response to system changes (see IEC 62933 Part 5-1 § 7.8.3). The same general principles are applicable to the safety design of a BESS (see IEC 62933 Part 5-2 § 7.8).

Additional general requirements for BESS safety are discussed in IEC 62933 Part 5-2 § 7.9, which focuses on the ability of failures or faults to be contained within subsystems, independent operation of safety functions of subsystems, minimization of noise, vibration and extreme temperatures, identification of hazardous conditions, prevention of remote dangerous operations, and ergonomics to reduce strain on operators.

4. ESS-Related Hazards

In addition to being safely located and enclosed, an ESS should be designed and installed to mitigate the risks posed by the hazards specific to the particular technology being utilized. Chapter 9 of NFPA 855 (see also NYBESSG at 50) identifies technology-specific requirements for addressing the hazards posed by various storage types (i.e., exhaust ventilation, spill control, neutralization, safety caps, thermal runaway, explosion control, and size and separation).

Table 3.1 of AS/NZS 5139 similarly identifies the types of hazards applicable to various battery types. AS/NZS 5139 § 3.2 requires safety data sheets and manufacturers' installation instructions to be provided specifically in relation to such hazards.

NFPA 855 also includes chapters specifically dedicated to (1) capacitor ESSs (see Chapter 10) and (2) fuel cell ESSs (see Chapter 11).

Some of the more common hazards posed by ESSs include electrical hazards, mechanical hazards, explosion hazards, fire hazards and chemical hazards. The sections below discuss measures for mitigating the risks posed by the various types of hazards posed by ESSs.

a. Electrical Hazards

In general, live parts of ESSs should be designed to guard against accidental human contact by means of an enclosure, fencing, guarding or other measures. Safe working practices should be required, including operation and maintenance instructions that provide for secure isolation and earthing of live conductors (where possible), appropriate personal protective equipment ("PPE"), signage, and risk of damage due to mildew or corrosion. Preventive measures against electrical hazards may include earth fault detection; over/under voltage, current and temperature detection; lightning protection; electrostatic dissipation; and fusing. In the event of unintentional islanding, the ESS should be designed to automatically disconnect from the grid. (See IEC 62933 Part 5-1 § 7.3.1.) However, automatic disconnection may not necessarily be required upon detection of islanding in systems that are specifically designed and allowed to intentionally island. (See id.)

In the case of BESSs, IEC 62933 Part 5-2 §§ 7.10.1 and 7.11.3.1 describe high-level best practices for protection from electrical hazards, including installation and protection standards, protection from electric shock, wiring and insulation requirements, physical spacing of circuits, prevention of short-circuits, lightning protection, safety-related components, protective devices, touch current and discharge energy, overcurrent protection, component redundancy and testing. (See also IEC 62933 Part 3-1 § 6.2.3.2 for insulation resistance and dielectric strength.) With respect to charge controllers, NFPA 855 § 4.2.7 requires compatibility with the ESS manufacturer's specifications and provides guidelines for listing and labelling. As discussed in Sections V.F.2 and V.F.3 below, NFPA 855 also includes end-user information requirements specific to first responders.

In order to simplify decisions associated with protection and enclosure requirements, AS/NZS 5139 § 3.2.3.2 requires that the decisive voltage classifications from IEC 62109-1 be applied to the classification of circuits for PCE (including inverters and charge controllers). In systems that have additional generation ports and other devices connected, AS/NZS 5139 § 4.3.1.1 specifies further requirements for their installation.

AS/NZS 5139 provides substantial guidance on arc flash energy hazards when working near live parts, including recommendations for work procedures, risk assessment, calculation of arc flash energy, operating time for the protection, multiplying factors for enclosures and rooms, PPE and other mitigation measures (see AS/NZS 5139 §§ 4.3.2, 5.3.2, 6.3.2). AS/NZS 5139 also includes different specifications for residential versus non-residential applications (see §§ 6.3.2.3, 6.3.2.4), as well as equations for calculating arc flash boundaries (see § 6.3.2.5).

IEC 62933 Part 5-2 § 8.2.1 provides validation and testing requirements for BESS safety features related to electrical hazards including high current discharge (short-circuit) protection (see § 8.2.1.1); overcharge, high current charge and earth fault protection (see § 8.2.1.2); impulse withstand voltage protection (see § 8.2.1.3); dielectric tests (see § 8.2.1.4); insulation resistance (see § 8.2.1.5); earthing system checks (see § 8.2.1.6); and anti-islanding (see § 8.2.1.7).

In the case of earthing systems, AS/NZS 5139 provides further requirements (see §§ 4.3.1.3, 5.3.1.6, 5.3.1.7), including monitoring alarms (see §§ 4.3.1.3.2 and 6.3.1.9); poles for live connections (see § 5.3.1.6.1); floating/separated systems (see §§ 5.3.1.6.2 and 6.3.1.8.2); direct earthed systems (see §§ 5.3.1.6.3 and 6.3.1.8.3); resistive earthed systems (see §§ 5.3.1.6.4 and 6.3.1.8.4); earth location (see § 5.3.1.6.6); and size of earth cable (see § 5.3.1.6.7).

i. Over Current Protection

Electric hazards related to over current are a major area of focus for ESS safety. Section 7.4 of IEC 62933 Part 5-1 provides general guidelines for over current protection of ESSs in general that are also applicable to BESSs (see IEC 62933 Part 5-2 § 7.4). More detailed requirements for over current protection are provided in AS/NZS 5139 § 5.3.1.2, including requirements for device locations (see §§ 5.3.1.2.5 and 6.3.1.2.5) and specifications (see § 5.3.1.2.1), as well as requirements specific to circuit breakers (see § 5.3.1.2.2), high rupturing capacity ("HRC") fuses and holders (see § 5.3.1.2.3), over current protection of output cables (see § 5.3.1.2.4), and battery systems not requiring a battery management system (see § 5.3.1.2.6). Similar requirements are also included in the New York Electrical Checklist (see NYBESSG at 27).

b. Mechanical Hazards

The basic safeguards against mechanical hazards of ESS systems are set forth in IEC 62933 Part 5-1 § 7.3.2 and include enclosure structural requirements, safety interlocks and means to stop motion of moving parts, robust handles and mounting means, and means to contain parts in the event of an explosion or mechanical failure.

In the case of BESSs, IEC 62933 Part 5-2 § 7.10.2 provides additional general guidance for addressing matters such as sharp edges, protection from moving parts, worker safety and handling of heavy equipment (see also NFPA 855 § 4.3.4; NYBESSG at 20; AS/NZS 5139 §§ 3.2.5, 4.3.3, 6.3.3.4). Where the battery type poses the risk of a self-sustaining fire due to puncturing of a cell, additional measures should be taken against mechanical damage from external forces (see AS/NZS 5139 § 6.3.4.10).

Additional requirements and recommendations for protection against mechanical hazards in BESS enclosures and rooms are provided in AS/NZS 5139 §§ 6.3.3.2 and 6.3.3.3, respectively (e.g., maximum deflection of racks under load, use of horizontal restraining bars, consideration of seismic effects). Further requirements for battery cell and module stands (e.g., limits on number of rows of batteries) are provided in AS/NZS 5139 § 6.2.7. The New York Electrical Checklist also includes a requirement that electrical connections should not put mechanical strain on battery terminals (see NYBESSG at 27).

IEC 62933 Part 5-2 § 8.2.2 provides validation and testing requirements for BESS safety features related to mechanical hazards, including enclosure strength against impact (see § 8.2.2.1) and static force (see § 8.2.2.2), as well as impact and vibration during transportation and seismic events (see § 8.2.2.3).

c. Explosion Hazards

IEC 62933 Part 5-1 § 7.3.3.1 lays out a basic framework for addressing explosion hazards in ESSs consisting of: (1) prevention (i.e., avoiding/reducing explosive atmospheres and ignition sources); and (2) protection (i.e., halting or limiting the range of the explosion), and recommends that guidance be sought from competent persons. In the case of BESSs, IEC 62933 Part 5-2 § 7.10.3 provides additional high-level recommendations related to the placement of flammable materials in the path of exhaust systems, the use of gas purging systems, and ventilation of flammable gases into enclosed spaces where they might be ignited. IEC § 62933 Part 5-2 § 7.11.3.3 provides specific explosion protection requirements for various categories of BESSs depending on their voltage, capacity, site occupancy and system chemistry.

Where provided and subject to local conditions, the manufacturer's recommendations on charging and ventilation should be followed (see, e.g., AS/NZS 5139 § 3.2.7), and air fans, conditioners and filters should be periodically inspected to ensure cleanliness, and quiet and smooth operation (see CA SED Checklist).

As further discussed below, NFPA 855 and AS/NZS 5139 provide additional detailed requirements and recommendations for addressing explosion hazards by way of (i) ventilation, (ii) explosion control, and (iii) gas detection systems.

i. Ventilation

NFPA 855 § 4.9 sets forth ventilation requirements for rooms, enclosures, walk-in units and cabinets, including maximum levels of flammable gas concentration, minimum mechanical exhaust ventilation rates, installation and supervision/signaling (see also NYBESSG at 27, 35, 38). More detailed discussion on ventilation requirements for BESSs that pose explosive gas hazards is provided in AS/NZS 5139 § 6.3.5.2, which includes requirements for:

- sealed valve-regulated acid cells (see § 6.3.5.2.2) as well as other battery system chemistries (see § 6.3.5.2.8);
- equations for calculating maximum hydrogen gas concentrations (see § 6.3.5.2.3);

- charging rates for chargers with and without automatic over-voltage cut-off (see § 6.3.5.2.4);[19]
- equations for calculating minimum inlet and outlet sizes for natural ventilation (see § 6.3.5.2.5);
- air flow rates for and limitations on the use of mechanical ventilation (see § 6.3.5.2.6); and
- requirements and recommendations for the arrangement and layout of ventilation systems (see § 6.3.5.2.7).

AS/NZS 5139 §§ 6.3.5.3 and 6.3.5.4 provide additional ventilation requirements specific to enclosures and rooms, respectively, including but not limited to requirements for the location of equipment that could cause sparks (including lighting), seals on doors and other openings, and location of over current protection devices and sockets.

ii. Explosion Control

NFPA 855 § 4.12 provides requirements for explosion control, including the design, installation, operation, maintenance and testing of explosion prevention systems, as well as the installation and maintenance of deflagration venting (see also NYBESSG at 50).

iii. Gas Detection Systems

Requirements for gas detection systems in rooms, walk-in units, enclosures, walk-in containers and cabinets containing ESSs are provided in NFPA 855 § 4.9.3.2, including minimum activation and de-activation levels, minimum duration of standby power, and trouble signals in the event of system failure (see also NYBESSG at 38, 40, 49).

IEC 62933 Part 5-2 § 8.2.3 provides validation and testing requirements for BESS safety features related to explosion hazards, including specification of flammable gas (see IEC § 8.2.3.1); gas detection/off-gas detection (see IEC § 8.2.3.2); and ventilation (see IEC § 8.2.3.3).

d. Electric/Magnetic/Electromagnetic Field Hazards

IEC 62933 Part 5-1 § 7.3.3.2 recommends that ESS systems should have sufficient immunity against electric, magnetic and electromagnetic disturbances/noise that could affect individual components or communications between components of an ESS, including BESS components for safety functions. IEC 62933 Part 5-2 § 7.10.4 includes high-level recommendations to mitigate the risks from such hazards. IEC 62933 Part 5-2 § 8.2.3 provides validation and testing requirements for BESS safety features related to such hazards.

e. Fire Hazards

In general, the design and installation of a BESS should minimize the potential for the spread of a fire originating in the battery system. NFPA 855 § 7.10.5 provides general guidance on protection from fire hazards, including non-combustible construction, separation of systems, risk assessments and testing (see also AS/NZS 5139). NFPA 855 § 4.1.6.1 prohibits the storage of combustible materials not related to ESSs in ESS rooms, cabinets or equipment. For combustible materials that are related to ESS equipment, NFPA 855 § 4.1.6.2 requires that the combustible materials be stored at a minimum distance from the ESS equipment (see also NYBESSG at 45). IEC § 62933 § 7.11.3.4 provides specific fire protection requirements for various categories of BESSs

[19] Electrical charging without cut-off can potentially impact ventilation (e.g., due to "boil-off").

depending on their voltage, capacity, site occupancy and system chemistry.

The fire hazard topics/measures addressed by the various codes covered in this report can generally be broken down into: (1) fire prevention; (2) fire resistance; (3) fire detection; and (4) fire suppression, each of which are discussed in turn below (see generally IEC 62933 Part 5-1 § 7.3.3.3). Periodic inspections should be conducted and records maintained to ensure compliance with such measures (see CA SED Checklist).

i. Fire Prevention

BESSs that pose fire hazards due to fault conditions are generally required to be installed with an energy storage management system (also referred to as a "battery management system") that monitors the potential fault conditions that could result in a fire. NFPA 855 § 4.2.9 includes requirements for the installation of systems for monitoring operating conditions and maintaining voltages, currents and temperatures within manufacturer's specifications, as well as notification of and electrical isolation under dangerous conditions (see also NYBESSG at 21, 44).

AS/NZS 5139 § 6.3.4.4 includes similar requirements, while also addressing situations where a battery system utilizes more than one battery chemistry. In addition, AS/NZS 5139 §§ 6.3.4.5 through 6.3.4.9 include detailed operating parameters, requirements and procedures for various specific types of hazardous conditions, including excess temperature, minimum temperature, over current, overvoltage and over-discharge.

ii. Fire Resistance

As noted in the discussion of ESS enclosures and rooms above, applicable electrical, building, residential and fire codes generally require such installations to be constructed of non-combustible materials with appropriate fire resistance ratings (see, e.g., NYBESSG at 21, 35). In this regard, AS/NZS 5139 § 4.2.4.2 provides specific parameters for testing materials for non-combustibility, a list of non-combustible materials that are exempt from testing, requirements for vents or perforations within fire barriers, and barrier requirements for BESSs placed near or against habitable rooms. AS/NZS 5139 also includes additional specific requirements for domestic versus non-domestic installations, depending on whether the potential fire hazard is self-sustaining or non-self-sustaining (see §§ 6.3.4.2 and 6.3.4.3).

iii. Fire Detection

In accordance with various provisions of the IFC, IBC and IRC, NFPA 855 § 4.10 specifies general requirements for smoke detectors in fire areas containing ESSs, as well as replacement of smoke detection systems with radiant energy-sensing detection systems (see also NYBESSG at 35, 37, 45, 48). AS/NZS § 4.3.4 provides additional guidance for detectors where a BESS is installed in a building with a fire indication panel.

iv. Fire Suppression

NFPA 855 § 4.11 (see also NYBESSG at 48; CA SED Checklist) provides detailed requirements for fire control and suppression for rooms or areas within buildings and walk-in units containing ESSs, including specific requirements for:

- sprinkler systems (see § 4.11.2);
- other automatic suppression systems (see § 4.11.3);
- various types of lead-acid and nickel-cadmium systems (see §§ 4.11.4-4.11.6);

- open parking garages (see § 4.11.7);
- dedicated-use buildings (see § 4.11.8); and
- outdoor walk-in enclosures (see § 4.11.9).

NFPA 855 also includes water supply requirements for fire suppression systems (see § 4.13), as well as measures for remediation after a fire or other event has damaged an ESS and poses a threat of ignition or re-ignition (see § 4.16).

IEC 62933 Part 5-2 § 8.2.4 provides validation and testing requirements for BESS safety features related to fire hazards. In addition, NFPA 855 § 4.1.5 provides requirements related to large-scale fire tests, to the extent required.

f. Temperature Hazards

In addition to temperature hazards related to fires and electrical faults, IEC 62933 Part 5-1 § 7.3.3.4, and Part 5-2 § 7.10.6 address thermal insulation/partitions, spacing, sensors, alarms and signage to protect against injury to workers as a result of coming into contact with hot parts of battery systems. IEC 62933 Part 5-2 § 7.11.3.5 also provides temperature hazard protection requirements related to the monitoring by operators of internal enclosure and subsystem temperatures.

IEC 62933 Part 5-2 § 8.2.6 provides validation and testing requirements for BESS safety features related to temperature hazards, including verification of thermal control operation (see § 8.2.6.1); abnormal operation of subsystems for ventilation (see § 8.2.6.2); and temperature under normal operation tests (see § 8.2.6.3). The CA SED Checklist similarly provides for periodic inspections to observe signs of localized overheating, structural defects and hotspots.

g. Chemical Hazards

IEC 62933 Part 5-1 § 7.3.3.5 and Part 5-2 § 7.10.7 provide general guidance on protection from hazardous substances and toxic gas, including containment of hazardous substances and other safeguards to protect against injury (e.g., alarms and PPE). More specific requirements for various categories of BESSs (i.e., depending on voltage, capacity, site occupancy and system chemistry) are provided in IEC 62933 Part 5-2 § 7.11.3.6. The CA SED Checklist also includes general guidelines for the implementation of hazardous materials policies and programs including record-keeping, manifests, safety data sheets, handling, storage and disposal, response plans and equipment.

i. Spill Control

NFPA 855 § 4.14 includes detailed spill control requirements for rooms and buildings containing ESSs, including spill containment system capacities and neutralization (see also NYBESSG at 50). Additional requirements to address spill control are provided in AS/NZS 5139, including requirements related to conformance with manufacturer requirements (see §§ 4.3.6 and 5.3.6); puncturing (see § 6.3.6.2); containment (including requirements for spill trays) (see § 6.3.6.3); and requirements related to the construction and layout of enclosures and rooms (see § 6.3.6.4).

ii. Toxic Fumes

NFPA 855 § 4.1.1 prohibits the release of toxic or highly toxic gases in rooms or spaces in excess of certain limits. Where ESSs that have the potential to release toxic or highly toxic gases are installed indoors, the IFC requires the installation of hazardous exhaust systems (see NYBESSG at 46). In addition, the IRC prohibits the installation of ESSs that have the potential to produce toxic or highly toxic gases in dwellings and townhouses (see NYBESSG at 35). Periodic inspections may include requirements to inspect SO_2 detectors and wind socks (see CA SED Checklist).

General requirements and recommendations for mitigating hazards related to toxic fumes are also provided in AS/NZS 5139 § 3.2.9. AS/NZS 5139 § 6.3.7.2 provides measures for mitigating toxic fume hazards in rooms and enclosures, including construction, natural ventilation and mechanical ventilation. AS/NZS 5139 § 6.3.8 provides further requirements for mitigating toxic fume hazards through the use of battery alarm systems.

IEC 62933 Part 5-2 § 8.2.7 provides validation and testing requirements for BESS safety features related to chemical hazards, including specification of hazardous fluids (see § 8.2.7.1); fluids detection; (see § 8.2.7.2); and protective measures against hazardous fluid (see § 8.2.7.3).

h. Subsystem Malfunctions

In the event of an auxiliary, control or communication system malfunction, IEC 62933 Part 5-2 § 7.10.8 requires that BESS equipment be designed to limit the risk of fire or shock and be able to enter a safe state automatically. IEC 62933 Part 5-2 § 8.2.8 provides validation and testing requirements for BESS safety features related to such hazards, including safety interlocks.

5. Safe System Operation

a. Disconnection and Shutdown

As discussed in IEC 62933 Part 5-1 § 7.5, disconnection and shutdown procedures are important for ensuring safety during ESS operation, maintenance and repairs. In this regard, IEC 62933 Part 5-1 § 7.5.1 discusses the general circumstances requiring disconnection of an ESS or some of its components, as well as different parts of ESSs where disconnection or partial disconnection may be achieved. IEC 62933 Part 5-1 also includes discussions of more specific topics related to ESS disconnection and shutdown, including:

- grid-disconnected state (see § 7.5.2);
- stopped state (see § 7.5.3);
- system shutdown (see § 7.5.4);
- cybersecurity (see § 7.5.5);
- partial disconnection (see § 7.5.6); and
- equipment guidelines for emergency shutdown (see § 7.5.7).

The considerations above are generally applicable to BESSs as well (see IEC 62933 Part 5-2 § 7.5). One of the common areas of focus for guards and protective measures as they relate to BESSs is isolation of subsystems to enable safe conditions for maintenance, repair, fault-finding and inspection (see IEC 62933 Part 5-2 § 7.11.2; AS/NZS 5139 § 5.3.1.3.1). In this regard, NFPA 855 § 5.2 requires a readily accessible disconnecting means for ESSs to be provided within sight an ESS (see also NYBESSG at 28, 45). General requirements for the use of isolating devices in grid connected state, stopped state and isolated conditions for maintenance are provided in IEC 62933 Part 5-2 §§ 7.11.2.2, 7.11.2.3 and 7.11.2.4, respectively.

More detailed requirements regarding disconnection means are provided in AS/NZS 5139. For example, AS/NZS 5139 § 5.3.1.3.2 requires BESSs to include one of the following load breaking disconnection methods: (1) an adjacent and physically separate disconnection device; (2) a disconnection device integrated into the PCE; or (3) a disconnection device integrated into the battery system. AS/NZS 5139 § 5.3.1.3.3 specifies requirements for switch disconnects used as load breaking disconnection devices, including type, ratings, minimum pollution degree classification and other capabilities. In the case of adjacent and physically separate disconnection devices, AS/NZS 5139 § 5.3.1.3.4 includes additional requirements for mounting in enclosures and ratings for ambient temperatures. In the case of disconnection devices integrated into PCEs, AS/NZS 5139 § 5.3.1.3.5 provides additional requirements related to replacement and removal, as well as mitigation of electrical hazards. In the case of disconnection devices integrated into battery systems, AS/NZS 5139 §§ 5.3.1.3.6 and 6.3.1.3.6 address internal isolation devices operating in all live conductors. AS/NZS 5139 also includes requirements related to the location of isolation devices (see § 5.3.1.3.7); BESSs with multiple PCEs (see § 5.3.1.3.8); parallel battery systems (see § 5.3.1.3.9); and interconnection isolating requirements (see § 6.3.1.3.10).

Requirements for the screening from touch of live parts are provided in AS/NZS 5139 § 6.3.1.4, including shrouding and insulation (see § 6.3.1.4.2); terminals and outgoing busbars (see § 6.3.1.4.3); and inter-tier and inter-row connections (see § 6.3.1.4.4). Requirements for the wiring of battery systems to PCEs are provided in AS/NZS 6139 § 6.3.1.5, including requirements related to types of cables (see § 6.3.1.5.2; see also NYBESSG at 26); mechanical protection (see §§ 5.3.1.5.3 and 6.3.1.5.3); voltage drop (see § 5.3.1.5.4); current carrying capacity (see § 5.3.1.5.5); parallel battery systems (see § 5.3.1.5.6); and protection from PCE overcurrent (see § 5.3.1.5.7). Requirements related to the segregation of circuits are provided in AS/NZS 5139 § 5.3.1.6, including requirements for insulating barriers, mounting and labelling, and cable colors (see also NYBESSG at 26).

b. Information for End Users

As discussed in turn below, information that should be provided to ESS end-users generally includes training, labels and signage, and alarm systems. In the case of a BESS, IEC 62933 Part 5-2 § 7.12 recommends various types of safety information that should be provided for end users, including warning devices, signs, signals and labelling. Guidelines and manuals should also be readily available to end users, as further discussed in Section V.F below.

i. Staff Training

Adequate staff training is a key requirement for the safe operation and maintenance of ESSs. IEC 62933 Part 5-1 § 7.7 provides a high-level discussion of the need for staff training on ESS-related hazards to promote work safety, including the contents, timing, participants and records of such training. NFPA 855 § 4.1.3.2.2 also provides requirements for the training of ESS facility staff. In addition, NFPA 855 § 7.2.5 includes general requirements on training for individuals involved in system operation and maintenance.

The same general principles are applicable to staff training for BESSs (see IEC 62933 Part 5-2 § 7.7). In addition, IEC 62933 Part 5-2 § 7.13.1.5 provides general staff training requirements specific to BESS suppliers and operators, including safety skills and information, training guidelines and manuals, and competence and authorization levels.

ii. Labels and Signage

Annex F of IEC 62933 Part 5-2 provides general guidance on the types of information that should be included in warning signs for BESS systems. Under the CA SED Checklist, periodic inspections should confirm that signage and placards are compliant with ANSI, NFPA and other applicable standards. In that regard, NFPA 855 § 4.3.5 includes signage requirements specific to ESSs, including required locations and types of information. NFPA 855 § 4.3.12 provides requirements for signage and documentation in buildings equipped with fire command centers.

NFPA 855 § 7.1.3 provides requirements regarding the posting of safety data sheets for hazardous materials.

Additional signage requirements are provided in the New York Model Law and Electrical Checklist, and IFC, including requirements related to types of technologies, special hazards, contact information, disconnect and emergency shut-off information, voltages, product information, symbols, over current devices, polarity, conductors and specific wording for certain warning labels (see NYBESSG at 10, 26, 29, 46).

Section 7 of AS/NZS 5139 includes even more specific requirements, recommendations and discussion regarding signage, including:

- design, construction, size, color and location (see § 7.2);
- labelling of battery type (see § 7.3);
- system location (see § 7.4);
- access restrictions (see § 7.5);
- voltage and current (see § 7.6);
- safety data sheets (see § 7.7);
- explosive gas, toxic fume, chemical and arc flash hazards (see §§ 7.8-7.11);
- disconnection devices (see § 7.12);
- over current devices (see § 7.13);
- cables (see § 7.14);
- segregation (see § 7.15);
- shutdown procedures (see § 7.16);
- battery labelling (see § 7.17);
- other equipment labelling (see § 7.18); and
- spill containment (see § 7.19).

One of the recommendations from AS/NZS 5139 provides for labels/signage to be in English. In the case of Thailand, consideration should be given to labels and signage in Thai, other government-recognized local dialects, and/or English, depending on the languages understood by end users and other local inhabitants.

iii. Alarm Systems

General guidance regarding the installation, placement, capabilities and instructions for battery alarm systems is provided in AS/NZS 5139 § 4.3.8. As it relates to specific hazards posed by different types of ESSs, further discussion of different types of alarm systems is provided in Section V.D.4 above.

c. Lifecycle Safety Management

As further discussed below, Section 7.13 of IEC 62933 Part 5-2 includes requirements for the safe operation, maintenance, repair and modification of BESSs over the course of their service lives. Annex E of IEC 62933 Part 5-2 provides information on best practices for confirming compliance with those requirements.

i. Preventive Maintenance

Section 7.6 of IEC 62933 Part 5-1 provides a high-level discussion of the importance of preventive maintenance, monitoring (including remote monitoring) and unattended operation of

ESSs. The same general considerations are also applicable to the operation and maintenance of BESSs (see IEC 62933 Part 5-2 § 7.6).

As parts of a BESS are replaced over its life span in connection with scheduled and unplanned maintenance, as well as design changes, the availability of safe and compatible parts may be limited. Where that is the case, IEC 62933 Part 5-2 § 7.13.1 requires that consideration be given to adverse long-term changes in the operation and maintenance of BESS systems. NFPA 855 §§ 7.1 and 7.2 require all ESSs to be operated and maintained in accordance with the manufacturer's instructions and operation and maintenance documentation.

ii. Alterations, Repairs and Retrofits

As noted above, the system design of a BESS or its components may change over the course of its service life. Where this is the case, IEC 62933 Part 5-2 §§ 7.13.2 and 7.13.3 provide a list of situations that require the reassessment of safety measures, areas of focus where such situations arise, and discussion of related safety design, risk analysis, safety plans and other considerations. Upon recommissioning of a system that has undergone and alteration, NFPA 855 § 7.2.5.2 requires training on any changes related to its operation and maintenance. Further requirements in the event of system alterations are provided in AS/NZS 5139 §§ 4.4.2.3 and 5.4.2.3.

NFPA 855 § 4.2.2 requires repairs to be carried out by qualified persons and adequately documented (see also NYBESSG at 45). Where a repair is considered a retrofit, NFPA 855 § 4.2.3 provides additional requirements related to equipment listings, installation requirements and documentation (see also NYBESSG at 45). In the case of ESS replacements and additions, NFPA 855 §§ 4.2.4 and 4.2.5 require compliance with the requirements for new ESSs (see also NYBESSG at 36, 45); provided however that an increase in maximum stored energy or power rating to an existing ESS may be treated as a retrofit (see NFPA 855 § 4.2.5.2). In addition, NFPA 855 § 4.2.4.2 requires replaced equipment to be decommissioned in accordance with NFPA 855 Chapter 8.

iii. Reused and Repurposed Equipment

NFPA 855 § 4.2.10 includes specific requirements regarding qualifications for entities engaged in repurposing used battery equipment, and the reconditioning and testing of such materials, equipment and devices.

iv. Storage of Used Batteries

Chapter 14 of NFPA 855 provides detailed requirements for the storage of used or off-specification batteries, including the areas where they may be stored, collection locations, storage methods, and special requirements for indoor versus outdoor locations.

v. Decommissioning and Dismantling

IEC 62933 Part 5-2 § 7.13.4 provides general guidance for the dismantling of BESS equipment and the end of its service life. More detailed requirements for decommissioning BESS equipment are set forth in NFPA 855, including requirements for decommissioning plans, decommissioning processes and decommissioning reports (see also NYBESSG at 10, 44). In addition, the New York Model Law includes provisions for decommissioning upon system abandonment (see NYBESSG at 13).

E. System Safety Validation and Testing

IEC 62933 Part 5-1 § 8 provides general guidance for safety testing ESS systems, including testing for auxiliary system malfunction (see § 8.2); control system malfunction (see § 8.3); internal communication malfunction (see § 8.4); and external communication malfunction (see § 8.5).

IEC 62933 Part 5-2 § 8.1 provides general guidelines for testing the effectiveness of BESS safety design features, guards and protective measures depending on the size, technology, location, exposure and complexity of the particular system, including requirements for type tests, FAT and SAT, as appropriate. Table 5 of IEC 62933 Part 5-2 identifies the types of safety tests that are required to address the various types of hazards that are posed by different types of BESSs. NFPA 855 §§ 6.1.6 and 7.3 require such testing to be carried out and documented as part of the commissioning process in accordance with manufacturers' instructions, and the New York Model Law lists applicable standards for testing the safety of BESS subcomponents (see NYBESSG at 13). AS/NZS 5139 § 4.4.2 provides specific requirements for initial verification and visual inspection and testing prior to placement of BESS installations into service. The New York Electrical Checklist lists items to be confirmed prior to and during such testing (see NYBESSG at 25-26). Some of the common items to be validated and tested include:

- fuses and breakers;
- earthing;
- connections;
- labels and signage;
- isolation devices;
- ancillary safety devices;
- alarms;
- plans, permit and installation instructions;
- system revisions;
- polarity; and
- voltages.

Validation and testing requirements specific to the various hazards posed by various types of BESSs are provided in IEC 62933 Part 5-2 § 8.2 and further discussed in Section V.D.4 of this report.

F. Guidelines and Manuals

To help facilitate the safe use of ESSs, Chapter 9 of IEC 62933 Part 5-1 identifies and provides requirements for four different types of guidelines and manuals: (1) user manuals; (2) emergency procedure manuals; (3) first response manuals; and (4) PPE guidelines, each of which are discussed in turn below. NFPA 855 §§ 7.1 and 7.2 include similar requirements for operation and maintenance documentation, including startup, inspection, testing, maintenance and operation procedures, safety data sheet considerations and maintenance records. The CA SED Checklist likewise requires periodic inspections to confirm that facilities have documented safety plans that address manmade and natural disasters such as wildfire, earthquake, flood, chemical spill, toxic gas release, explosion, terrorism, etc. Having such documentation on-hand ensures that key system information is readily available to system operators, maintenance providers, inspectors and emergency responders (see also IEC 62933 Part 5-2 § 7.13.1.2).

1. User Manuals

In general, ESS user manuals should contain facility descriptions, safety rules, instructions for installation, commissioning and interface control, maintenance and troubleshooting procedures, and decommissioning requirements. Prior to installation of an ESS, NFPA 855 § 4.1.2 (see also NYBESSG at 41) provides requirements for the contents of construction documents submitted for approval by appropriate authorities, including plans and specifications (see §§ 4.1.2.1.1 and 4.1.2.1.2); test data, evaluation information and calculations (see § 4.1.2.1.3); and modeling results (see § 4.1.2.1.4), and further requires that such information be provided to the building owner (see § 4.1.2.2) and made accessible to facility personnel, fire code officials and emergency responders (see NFPA 855 § 6.3).

NFPA 855 § 4.1.2.3 provides requirements for the contents of operations and maintenance manuals including system size, routine maintenance actions, contact information, intended operations, and service logs (see also NYBESSG at 26, 44). Subject to certain exceptions, NFPA 855 § 4.2.1 requires ESS equipment to be listed in accordance with UL 9540. Similar to the requirements for construction documents above, NFPA 855 § 4.2.3.3.1 requires that operations and maintenance manuals be accessible to emergency responders. AS/NZS 5139 §§ 4.4.1.2, 5.4.1.2 and 6.4.1.2 include similar system manual requirements, including commissioning dates, model descriptions and serial numbers, system connection diagrams, risk assessments, spare part listings, and recommendations for recycling upon decommissioning. With respect to spare part listings, the CA SED Checklist requires that facilities be periodically checked for onsite spares, maintain periodic parts replacement lists, and replenish spare parts as needed.

2. Emergency Procedure Manuals

The contents of emergency procedure manuals generally should include:

- procedures to mitigate the consequences of major accidents caused by foreseeable events;
- measures for limiting risks to personnel;
- measures for providing early warning to those responsible for initiating emergency plans; and
- measures for training staff and coordinating off-site emergency services.

Additional requirements for emergency planning and training are provided in NFPA 855 § 4.1.3, which requires ESS owners to provide training for facility personnel and emergency responders to address foreseeable hazards associated with ESSs (see NFPA 855 § 4.1.3.1), including an on-site emergency operations plan that details procedures for system shut-down/ de-energization/ isolation/ restart, inspection and testing, response, hazard mitigation, and damaged equipment (see NFPA 855 § 4.1.3.2).

3. First Response Manual

The first response manual should provide procedures, roles and responsibilities for fire mitigation and suppression. In this regard, the CA SED Checklist requires overall safety plans to include outreach to first responders and local authorities (e.g., through training and periodic drills with fire, police, hazmat, etc.).

4. PPE Guidelines

Guidelines for PPE should include information and cautionary signage and precautions on the appropriate PPE required to perform various tasks (e.g., PPE for arc flash).

VI. ESS INTERCONNECTION

As discussed in turn below, the requirements and guidelines for the interconnection of inverter-based resources generally fall into two categories: (1) transmission-level interconnections; and (2) distribution-level interconnections.

A. Transmission-Level Interconnections

Two recent Reliability Guidelines published by NERC provide in-depth and up-to-date guidance on best practices for the interconnection of inverter-based resources to bulk power systems. The NERC 2018 Guideline[20] provides recommended steady-state and dynamic performance characteristics for inverter-based resources based in part on lessons learned from disturbance analyses following fault events that were caused by wildfires in the western United States in 2016 and 2017. Some of the topics covered in the NERC 2018 Guideline include:

- Measurement Data and Performance Monitoring.
- Momentary Cessation;
- Active Power-Frequency Control;
- Reactive Power-Voltage Control; and
- Inverter-Based Resource Protection.

Of note, Appendix A to the NERC 2018 Guideline provides recommended performance specifications, including: (1) general requirements for inverter-based resources; (2) momentary cessation mitigation and behavior; (3) fault ride-through, and frequency and voltage protection philosophies; (4) steady-state and dynamic active power-frequency control; and (5) steady-state and dynamic reactive power (current)-voltage control.

Currently underway, the IEEE P2800 standard effort is developing a performance-based standard to establish the "interconnection capability and performance criteria for inverter-based resources interconnected with transmission and networked sub-transmission systems. Included in this standard are recommendations on performance for reliable integration of inverter-based resources into the [bulk power system]." However, the development and adoption of the IEEE P2800 standard is expected to take multiple years. As a result, the NERC 2019 Guideline[21] was developed to bridge the gap between the current state and future adoption of the IEEE P2800 standard and included the findings from the analysis of two additional fault events in April and May of 2018[22] that resulted in loss of power from PV facilities. In addition to the items covered in the

[20] North American Electric Reliability Corporation, Reliability Guideline BPS-Connected Inverter-Based Resource Performance, September 2018. [online] Available at: https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Inverter-Based_Resource_Performance_Guideline.pdf. [Accessed 16 March 2021].

[21] North American Electric Reliability Corporation, Reliability Guideline Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources, September 2019. [online] Available at: https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf. [Accessed 16 March 2021].

[22] North American Electric Reliability Corporation, 2018. April and May 2018 Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report. [online] Available at: https://www.nerc.com/pa/rrm/ea/April_May_2018_Fault_Induced_Solar_PV_Resource_Int/April_May_2018_Solar_PV_Disturbance_Report.pdf. [Accessed 16 March 2021].

NERC 2018 Guideline, the NERC 2019 Guideline includes recommended improvements to interconnection requirements related to:

- Phase Jump Immunity;
- Capability Curves;
- Fast Frequency Response ("FFR");
- Reactive Power and No Active Power Output;
- Inverter Current Injection During Fault Conditions;
- Return to Service Following Tripping;
- Balancing;
- Operation in Low Short-Circuit Strength Systems;
- Grid Forming;
- System Restoration and Blackstart Capability;
- Protection Settings; and
- Power Quality.

However, it is noted that the 2019 NERC Guideline does not include a listing of recommended performance specifications (similar to those provided in Appendix A of the 2018 NERC Guideline) for the types of issues listed above. Such specifications may be forthcoming in a future NERC or IEEE publication, such as the IEEE P2800 standard.

Thailand's existing code for transmission system interconnections, *Connection Code for EGAT Network* ("EGAT Code") is relatively new – published in 2019. The general organization of the EGAT Code sets forth requirements for:

- Power producers with PPAs > 90 MW;
- Power producers with PPAs not exceeding 90 MW;
- Hydro floating solar;
- Third-party access;
- Guidelines for coordination with distribution utilities; and
- Other types of power generators.

Of note, the provisions in the EGAT Code for "other types of power generators" include a set of requirements for inverters in general (e.g., full-converter wind turbines, doubly-fed induction generators ("DFIG"), DPV, BESS) (see Section CC5.5.7-O), as well as an additional set of requirements specific to the interconnection of ESSs (e.g., design, procurement and installation characteristics, frequency requirements, voltage requirements, and step response times and ramp rates) (see Section CC5.4-O). Moving forward, it is recommended that the EGAT Code be updated as appropriate to take into account the recommendations for inverter-based systems set forth in the NERC 2018 and 2019 guidelines, as well as the IEEE P2800 standard (once it becomes available).

Table 2 below provides an outline of the topics covered in the NERC 2018 and 2019 Guidelines, along with high-level assessments of their current coverage under the existing EGAT Code:

Table 2. Coverage of NERC 2018 and 2019 Guideline Topics in the EGAT Code

NERC Guidelines	
Topic	**EGAT Code**
Measurement Data and Performance Monitoring	Partially covered in section CC8-P and CC8-S for all generation types. Section 0 of the Recommended Performance Specification in the 2018 NERC Guideline provides additional requirements for Measurement Data and Performance Monitoring for inverter-based systems.
Momentary Cessation	Not covered. Section 1 of the Recommended Performance Specification in the 2018 NERC Guideline provides performance requirements for Momentary Cessation. Momentary Cessation should be avoided within the voltage and frequency ride-through range.
Fault Ride-Through and Protection	Partially covered in section CC5.5.3-S. Section 2 of the Recommended Performance Specification in the 2018 NERC Guideline provides more detailed requirements for fault ride-through and protection for inverter-based generation including ride-through requirements for instantaneous and RMS voltage measurements.
Active Power-Frequency Control	Partially covered in section CC5.5.2-S. Section 3 of the Recommended Performance Specification in the 2018 NERC Guideline provides more detailed requirements for Active Power-Frequency Control including frequency measurement and response times.
Reactive Power-Voltage Control	Partially covered in section CC5.5.3-S. Section 4 of the Recommended Performance Specification in the 2018 NERC Guideline provides more detailed requirements for fault ride-through and protection response time for reactive power for small disturbances and reactive current for large disturbances.
Phase Jump Immunity	Not Covered. Transmission owners ("TOs") should establish a dialogue with interconnecting generation owners ("GOs") to understand the means in which the inverters may trip on instantaneous changes in phase (either due to fault events or line switching events). TOs may perform system studies to identify possible worst-case phase jumps at the point of interconnection ("POI") of the interconnecting resources. TOs may consider identifying worst case balanced phase jump limits or state that inverter-based resources should not trip for studied credible contingency events (similar to fault ride through ("FRT")).
Capability Curves	Not Covered. TOs should require that newly interconnecting inverter-based resource owners (along with all GOs) provide a "composite capability curve" that includes the overall active and reactive capability of the resource at the point of measurement ("POM").[23] This includes a complete P-Q graph (or table of data representing these data points) at nominal voltage.[24] Note that the reactive capability within that curve should be "dynamic". TOs may also require that the capability curve of each type of individual inverter be provided, since this helps verify aggregate capability in the planning models (along with the overall capability curve provided).
FFR	Not covered. Interconnection studies should identify system needs for FFR, and the TO should ensure the capability is available for grids where FFR may be needed. Requirements should be clear in stating whether non-sustained forms of FFR are acceptable and any additional requirements pertaining to the timing aspects of FFR. These issues are not specific to inverter-based resources, yet the TO should ensure sufficient frequency response capability to arrest large frequency deviations for credible contingency events.

[23] This is the "high-side of the generator substation" transformer.

[24] Requirements should be clear in identifying the voltage range for which the reactive capability requirements apply. This provides inverter manufacturers with information to suitably design the reactive capability for each project.

NERC Guidelines	
Topic	**EGAT Code**
Reactive Current-Voltage Control	Partially covered in section CC5.5.3-S. TOs should ensure that the large disturbance behavior from inverter-based resources provides dynamic voltage support through their reactive current-voltage controls, when voltage falls outside the continuous operating range of the inverters (and local inverter controls take over). This includes both the magnitude and timing of reactive current injection, and the prioritization between reactive and active current.
Reactive Power and No Active Power Output	Not covered. TOs may require inverter-based resources to exchange reactive power with the transmission system (to provide voltage control) when no active power is generated.
Inverter Current Injection During Fault Conditions	Partially covered in CC5.5.3-S. TOs should clearly articulate expected inverter behavior during and immediately following fault events in coordination with the small disturbance active and reactive current controls. This includes the magnitude of the current, the phase relationship of current with respect to voltage, and the timing of current injection. TOs may consider, based on detailed system studies (likely electromagnetic transient ("EMT") studies), establishing fault current requirements for newly interconnecting inverter-based resources since this response is dominated by the controls programmed into the inverter. As the penetration of inverter-based resources continues to grow, pockets of the transmission system may require unconventional relaying techniques to ensure secure protection schemes. The IEEE P2800 effort should consider standardizing fault current injection for inverter-based resources after further deliberation
Return to Service Following Tripping	Partially covered in CC5.5.3-S. TOs should specify the expected performance of inverter-based resources following a tripping event. This may include automatic reconnection after a predefined period of time or may include manual reconnection. Ramp rates during return to service conditions should be specified as well. Following "system black" conditions, inverter-based resources should not attempt to automatically reconnect to the grid (unless directed by the TO) so as to not interfere with blackstart procedures.
Balancing	Not covered. TOs should require the capability to limit active power ramp rates (in both directions) to mitigate any significantly large power swings over a short period of time, depending on weather when applicable. This is a balancing ramp rate typically expressed in terms of percentage output change per minute. Inverter-based resources should be required to receive automatic generation control ("AGC") dispatch signals if the market/agreement structure indicates this.
Operation in Low Short-Circuit Strength Systems	Not covered. TOs should ensure they understand and have studied areas of their systems where potential low short-circuit strength conditions could occur. TOs should have sufficient requirements in place to reliably study and integrate inverter-based resources into the transmission system, including these areas. In situations where potential low short-circuit strength conditions could occur (now or in the foreseeable future), the TO should ensure they have sufficient data and information needed to perform studies in these areas. This includes coordination with the GO, particularly during the interconnection studies process, to obtain EMT models or provide the GO with sufficient information to prove reliable control and capability to operate in these types of conditions.[25] Refer to Chapter 2 of the September 2019 NERC Reliability Guidelines for a more detailed description of the recommended process for coordination between the TO and GO and considerations for developing effective requirements to ensure sufficient data and information is exchanged prior to plant commissioning.

[25] The TO may choose to perform these studies, in which case necessary data from the GO needs to be provided (in coordination with the inverter manufacturer). In other cases, the TO may establish requirements for these studies to be performed by the GO and results provided to the TO for further consideration and approval.

NERC Guidelines	
Topic	**EGAT Code**
Grid Forming	Not covered. TOs should thoroughly understand when and where grid forming inverter capability may be needed on the transmission system prior to specifying its use in any interconnection requirements. Its use may include systems with a high penetration of inverter-based resources (localized or widespread) or systems that may be utilizing inverter-based resources for blackstart purposes. The industry is still developing the technology for large-scale grid forming inverters and its recommended use is in conjunction with other solution options. If the inverters employ grid forming technology, this information should be provided to the TO.
System Restoration and Blackstart Capability	Not Covered. While not specifically part of the interconnection requirements, two considerations worth highlighting include the following: • During system restoration, the TO typically requires coordination and instruction prior to a GO returning to service. This should be explicitly stated such that inverter-based resources do not unexpectedly automatically reconnect during the system restoration process. • Inverter-based resources are not required to have blackstart capability; however, if they do, that information should be provided to the TO as part of the interconnection process.
Protection Settings	Specific requirements for inverter-based generation not covered. TOs should review the key findings and recommendations from the disturbance reports involving solar PV resource tripping, and may consider incorporating these findings into interconnection requirements, as applicable. This may include: • Clarification that inverter protection should be set at the limits of equipment safety and reliability. • Tripping on calculated frequency should be based on an accurately calculated and filtered measurement over a time window and should not use an instantaneously calculated value. • Inverter overvoltage protection should be set as high as possible within equipment limitations. Ride-through curves should use a filtered RMS voltage measurement and should not be applied for transient, sub-cycle over voltages. • The TO should specify expected performance during successive fault events within a predefined period of time. • Any DC reverse current protection and phase lock loop ("PLL") loss of synchronism should not result in inverter tripping, in most cases, for transmission system fault events within the "No Trip Zone". Tripping within the "No Trip Zone" should be allowed for inverter faults that can lead to failure. • Inverter rate-of-change-of-frequency ("ROCOF") protection should be disabled unless an equipment limitation exists that requires the inverter to trip on high ROCOF. In most instances, ROCOF protection should not be used for transmission connected resources.
Power Quality	Partially covered in CC3-S and CCA7. TOs should specify recognized outage scenarios for inverter-based resources to assess power quality impacts. Inverter-based resources may request TOs to provide grid harmonic impedance characteristics (from TO reliability studies), in particular reactive facility data, in order to manage potential resonance issues. TOs may measure background power quality indices prior to inverter-based resource interconnections for design reference and later power quality responsibility separation. Permanent power quality monitoring is recommended for commercial operations. As needed, TOs should characterize actual harmonic distortion performance during the trial operation (during plant commissioning) period prior to the commercial operation date. Any harmonic distortion issues should be addressed based on the requirements established by the TO. The TO should require that the GO provide advanced notice prior to implementing firmware updates to the facility as firmware updates can improve or degrade power quality performance.

B. Distribution-Level Interconnections

In comparison to Thailand's EGAT Code for transmission-level interconnections (which was adopted in 2019), Thailand's codes for distribution-level interconnections are relatively older; the MEA Code and PEA Code were published in 2015 and 2016, respectively.

Since that time, electric grids around the world have undergone rapid changes in generation and resource mixes with increasing amounts of inverter-based generation. In particular, the recently-published IEEE 1547-2018, a revision of IEEE 1547-2003, made substantial changes to the original standard requirements for distribution-level interconnections, including but not limited to ride-through, active power-frequency control and reactive power-voltage control. Although the requirements in IEEE 1547-2018 technically apply only to distribution-connected resources, the updated standard aligns with transmission-level interconnection requirements in some aspects. The expanded capabilities required in these standards not only help to maintain the safety and reliability of the power system but also help to increase the feeder and system penetration limits for inverter-based generation. In anticipation of the wide-spread adoption of the IEEE 1547-2018 and the associated IEEE 1547.1-2020 and the September 16, 2020 UL 1741 update, manufacturers have already placed compliant inverters that meet the updated requirements in these standards into the market.

To facilitate the interconnection and parallel operation of DPV generating facilities with the EDL distribution system, a proposed new addition to the EDL Code provides general technical guidelines, requirements and procedures for DPV interconnection. For convenience, a copy of a document that reflects HNEI Grid***START***'s recommended new additions to the EDL Code is provided as Appendix 1 to this report. Given the geographic proximity and other similarities between the Lao and Thai distribution systems, it is recommended that similar updates could be made to the MEA Code and PEA Code. Table 3 below provides an outline of the topics covered in the EDL Code, along with high-level assessments of their current coverage under the existing MEA and PEA codes:

Table 3. Coverage of EDL Code Topics in the MEA and PEA Codes

EDL Code	MEA Code	PEA Code
Definitions	Covered	Covered
General Interconnection Guidelines		
Compliance with Laws and Codes	Not covered	Not covered
Interpretation	Not covered	Not covered
Notification for Supplemental Review	Covered in section 4.1.2	Covered in section 5.2
Export of Power	Not covered	Partially Covered in section 5.1.2 and section 5.2
Distribution System Feeder Penetration	Covered in section 6.1.1 through 6.1.3	Covered in section 4
(Low Voltage) Network Interconnection	Not covered. May not be applicable to MEA	Not Covered. Likely not applicable to PEA
Short Circuit Contribution Ratio	Covered in section 4.1.1(3)	Covered in section 5.1.3
Integration with Utility Grounding and Ground System Protection	Not covered	Not covered
Transformer Winding Configuration	Covered in section 4.3.2 and the single line diagrams in	Not covered

EDL Code	MEA Code	PEA Code
	Attachment 2	
Interconnection of Generating Facility	Covered in section 4.3.10	Covered in section 3
Generating Facility Design Requirements		
Isolation Device	Covered in section 4.3.1 and in the single line diagrams in Attachment A	Covered in general in section 7.1.1 and shown on the single line diagrams in Attachment 1
Interrupting Device	Covered in section 4.3.3	Covered in general in section 7.1.2
Supervisory Control	Covered in sections 4.6 and 4.7	Covered in sections 8.6 and 9
Equipment Testing	Partially covered in section 4.1.3 and Attachment 3	Partially covered in Attachment 6
Generating Facility Operating Requirements		
Disconnection of Generating Facility for Utility Reasons	Not covered	Not covered
Personnel and System Safety	Partially covered in sections 4.3.8 and 4.3.9	Not covered
Synchronization	Not covered	Not covered
Voltage Regulation	Partially covered in section 4.5.1. Should be updated.	Partially covered in sections 5.1.2 and 8.1. Should be updated.
Unintentional Islanding	Covered in section 4.4.4	Covered in section 12.4
Disconnection of Faults	Covered in section 4.4	Partially covered in section 7.1.11
Voltage Disturbances		
Maximum Trip Time	Covered in section 3.2 of Attachment 8. Consider allowing inverters to remain connected longer during undervoltage conditions.	Covered in section 12.3. Consider allowing inverters to remain connected longer during undervoltage conditions.
Voltage Ride-Through	Not Covered	Covered in section 12.2. Should be updated to include a ride-through for all generation types.
Return to Service	Covered in section 3.2.4	Covered in section 12.5
Volt-Watt	Not covered	Not covered
Frequency Disturbances		
Maximum Trip Time	Covered in section 4.5.2	Covered in section 8.2
Frequency Ride-Through	Not covered	Not covered
Frequency-Watt	Not covered	Not covered
Inadvertent Energization, Operation During Utility System Outage	Not covered	Not Covered
Required Delay on Reconnection	Covered in section 3.2.4	Covered in section 12.5
Loss of Protection	Partially covered for RTU failure in sections 5.2.3, 6.2.1(3) and 7.2.2(3)	Not covered
Reclosing Coordination	Covered in section 4.4.3	Covered in sections 7.1.4 and 7.1.5

EDL Code	MEA Code	PEA Code
Fixed Power Factor	Covered in section 4.5.1	Covered in section 8.1.2
Voltage Flicker	Covered in section 3.1.2 in Attachment 8	Covered in section 8.3
Harmonics	Covered in section 4.5.4. and section 2.3, 2.4 and 3.1.1 in Attachment 8	Covered in section 8.4
Direct Current Injection	Covered in section 3.1.3	Covered in section 8.5
Protection from Electromagnetic Interference (Immunity Protection)	Not covered	Not covered
Volt-Var Operations	Not covered	Not covered
Ramp Rate Requirements	Partially covered in section 4.5.2. Consider adding the capabilities to limit ramp rates on startup and during normal operation.	Partially covered in section 12.1. Should be updated. Consider adding the capabilities to limit ramp rates on startup and during normal operation.
Limiting of Overvoltage Contribution	Not covered. Overvoltage must disconnect requirements are covered in Section 3.2.1 of Attachment 8, but there is no limit on overvoltage magnitudes prior to disconnection.	Not covered. Overvoltage must disconnect requirements are covered, but there is no limit on overvoltage magnitudes prior to disconnection.
Remote Reconnect/Disconnect	Not covered	Not covered
Remote Configurability	Not covered	Not covered
Default Activation States for Functions	Not covered	Not covered
Protection, Synchronizing, and Control Requirements		
Protection Requirements	Generally covered by protection requirements in the MEA code.	Covered in sections 7, 8.2 and 12.3
Suitable Equipment	Covered in Attachment 8. Consider updating it to UL 1741SB, IEEE 1547-2018 and IEEE 1547.1-2020	Covered in Attachment 2. Consider updating it to UL 1741SB, IEEE 1547-2018 and IEEE 1547.1-2020
Review of Design Drawings	Not covered	Not covered

While there are many requirements covered in the IEEE 1547-2018 standard, there are several key requirements that should be highlighted in consideration of a higher penetration level of DER such as DPV systems and BESSs. Examples of key requirements and inverter grid-interactive functions that are recommended to be incorporated or updated in Thailand's codes include:

1) voltage and frequency disconnection and ride-through requirements;
2) volt-watt function;
3) frequency-watt function;
4) volt-var function;
5) limiting of overvoltage contribution; and
6) ramp rate requirements.

1. Voltage and Frequency Disconnection and Ride-Through Requirements

When IEEE 1547-2003 was adopted the anticipated level of DER to be connected to the power system was negligible. As such, DER were required to disconnect from the system as soon as a significant system disturbance was detected. With high levels of DER in place on many grid systems today, this is no longer the case. Therefore, while DER systems do need abnormal voltage and frequency protection to avoid islanding and equipment damage, DER can and should support the system during disturbances to the full extent of its designed capability, provided that it does not infringe on its protection requirements. The IEEE 1547-2018 standard allows for a wider range and longer duration of voltage and frequency ride-through than the 2003 version.

Distribution system operators, in coordination with TOs, should specify both disconnection (shall trip) and ride-through (shall remain connected) requirements during voltage and frequency disturbances based on their system performance during anticipated loss of generation and system fault events that are within the standard limits.

2. Volt-Watt Function

The volt-watt function, shown in Figure 2 below, is a new grid-interactive function that is specified in the IEEE 1547-2018 standard, along with the frequency-watt and volt-var functions discussed below. This function enables the inverter to reduce its real power output to help mitigate overvoltage events. While there is some risk of curtailment by activating this function, it may avoid the disconnection of the inverter and neighboring inverters due to high voltage at 1.10 pu voltage. Also, while this capability is required in the EDL Code, it is not required to be activated unless there is a need to mitigate an overvoltage interconnection concern due to high DER penetration levels on a circuit. In other words, this function, along with the volt-var function, can be used to enable the connection of more DER systems.

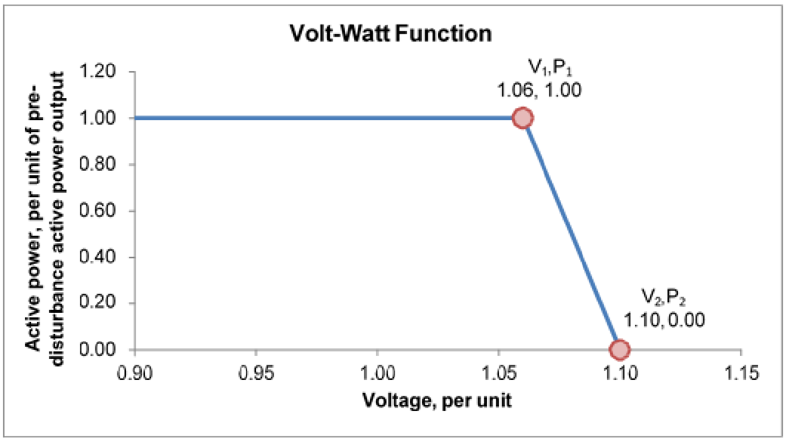

Figure 2. Diagram representation of the volt-watt function

3. Frequency-Watt Function

The frequency-watt function, shown in Figure 3 below, reduces the power output of the DER system to support the mitigation of over-frequency events. This watt reduction function initiates at the active power output level of the DER system when the over-frequency event starts. Since these over-frequency events are not common and are usually short lived, this function is required to be active in all DER systems.

When the level of variable generation, such as wind and solar resources, gets very high on a power system, the contribution to system downward reserve provided by the frequency-watt function is required to assist in the management of loss of load events. The assessment of loss of load events becomes an important metric in managing excess energy events that may otherwise at times require wind and solar resource curtailment if the provision of system downward reserves were provided solely by conventional generation resources. Enabling this function in all variable generation systems allows them to contribute to the provision of required downward reserves, and thereby be a part of the solution to reduce renewable excess energy curtailment. However, this is only effective if a significant number of systems are participating in downward reserve response. Hence, the earlier this function is implemented, the better.

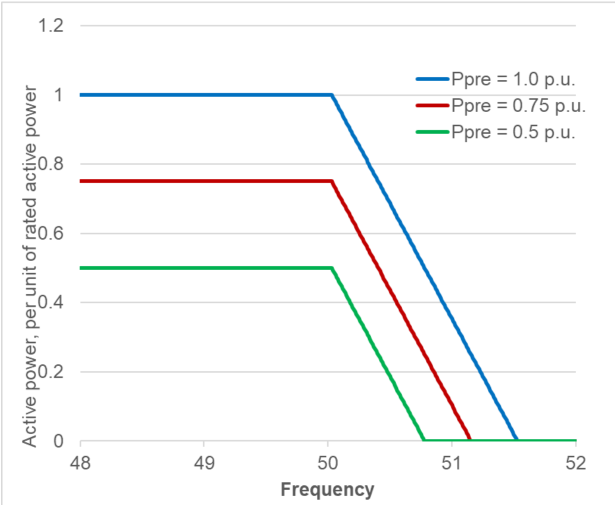

Figure 3. Diagram representation of the frequency-watt function

4. Volt-Var Function

One of the common concerns with DER interconnection is maintaining service voltage levels within the allowable voltage range. Allowing DER to regulate system voltages is another major change in philosophy in IEEE 1547-2018. The 2003 version did not allow DER to regulate voltage since the level of penetration was assumed to be minimal and the complication of adding additional regulating resources was perceived not worth the assumed minimal benefit. At the high levels of penetration today, this is again no longer the case. As DER interconnection pushes the limits of allowable voltage ranges, the volt-var requirement enables the DER system to become part of the solution. As voltages start to encroach on the boundaries of the allowed voltage range, the volt-var function shown in Figure 4 below will utilize its var import/export capability to maintain voltage within the allowed range. Again, this function is required in the EDL Code because a significant number of systems need to participate in order for it to be effective. Therefore, it is advantageous to require this function early in the establishment of interconnection standards. While there is a potential that the volt-var function may at times result in some limited real power curtailment due to inverter kVA limitations, this typically happens only at very high penetration levels and during maximum production and/or low load periods. Notwithstanding, the volt-var function enables the DER system to help effectively mitigate an issue that they may on occasion cause.

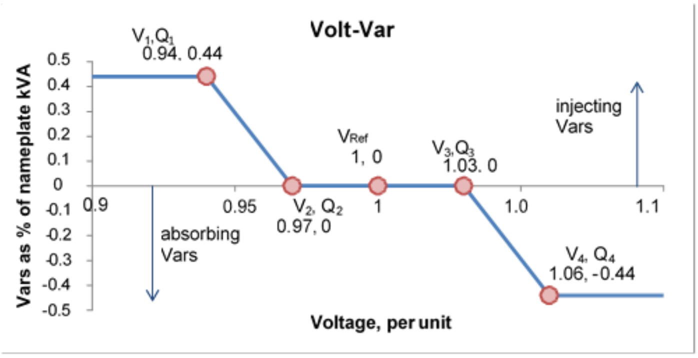

Figure 4. Diagram representation of the volt-var function

5. Limiting of Overvoltage Contribution

Without overvoltage contribution mitigation capability, inverter-based generation can cause damaging overvoltage levels on distribution systems that are serving customers. This typically happens when inverter-based generation is being exported through a disconnecting device such as a fuse or substation breaker, and the connected load on the system is not large enough to suppress the temporary overvoltage that occurs between the time the disconnecting device opens, and the inverter protection ceases to energize the system. Another typical situation that causes damaging overvoltage is when the generation to load ratio is greater than 120%. This overvoltage limitation function is required in the proposed EDL Code because it is beneficial to the grid and allows for higher penetration of DER systems if more inverters have this capability.

6. Ramp Rate Requirements

At high penetration levels of DER interconnections, the recovery from large system outages can be challenging. A few minutes after the restoration of the power system, the DER systems will all start to automatically reconnect. Requiring a Soft Start Ramp Rate creates a smoother transition as DER systems start up. Normal Ramp Rates during normal operation may be needed for larger systems. As such, the Normal Ramp Rate is not limited in the proposed EDL Code by default, but a limit can be set if needed to support interconnection.

VII. CONCLUSION

A multitude of recently-published guidelines, codes and standards for ESS integration have been published to help streamline the process of safely and effectively deploying ESSs for various applications throughout the world. The publications are voluminous, and their scopes cover a broad variety of topics including but not limited to categorization of technologies, system design, specifications and testing, environmental issues, safety considerations, and interconnection requirements. This report is intended to serve as a tool for identifying the key considerations and provisions as they relate to the latest guidance on ESS-related topics.

At a high level, the safe installation, operation and interconnection of BESSs in different types of environments has arisen as a common thread in the work being done to assess best practices for the integration of ESS technologies. For Thailand, the development and approval of guidelines for BESS interconnection and development will play a key role in accelerating the increased deployment of renewable energy in furtherance of renewable energy goals. In particular, Thailand's warm and humid tropical rainforest and monsoon climates (including its exposure to flood conditions), as well as its diverse energy resources, electricity loads and demographics, are key considerations that should be taken into account in the evolution of BESS development and transmission- and distribution-level interconnection requirements for inverter-based resources that are specifically tailored to Thailand's local and national power system conditions.

As the energy storage landscape continues to evolve in Thailand and throughout the world, there will undoubtedly be new developments in ESS technology and best practices. Toward that end, standards, codes, and guidelines ultimately adopted based on this report may need to be updated from time to time, as ESS technologies advance, and become more widely deployed and operated in different contexts.

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Électricité du Laos Distributed Solar Photovoltaic Generating Facility Interconnection Standards

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Consistency with Codes and Standards

The following interconnection standards are intended to provide general technical guidelines, requirements and procedures to facilitate the interconnection and parallel operation of distributed solar photovoltaic (PV) generating facilities with the electrical distribution system of Électricité du Laos (EDL). If there is a conflict between the technical specifications set forth in these standards with any technical specifications set forth elsewhere in EDL's interconnection requirements, the specifications of these standards shall prevail. The specific characteristics or needs of each distributed PV generating facility may reduce or increase its interconnection requirements. The degree of technical review required for a request for interconnection, and the extent to which an Interconnection Requirements Study (IRS) may be needed, will depend on factors such as the size of the generating facility, the type of technology and the point on EDL's system at which the distributed generating facility will be interconnected. These technical interconnection requirements have been established to maintain safety, reliability, and power quality standards for all EDL customers and personnel under the objectives of Good Interconnection Practice as described below:

- **Safety** – To protect the safety of EDL personnel, EDL customers, and the public.
- **Reliability** – To maintain the reliability of EDL's Electric Power System for all EDL customers.
- **Power Quality** – To provide for acceptable power quality[1] and voltage regulation on EDL's Electric Power System and for all EDL customers.
- **Restoration** – To facilitate restoration of power on EDL's Electric Power System.
- **Protect EDL and Customer Equipment** – To protect EDL and customer equipment during steady state and faulted system operating conditions.
- **Protect Generating Facilities** – To protect generating facilities from operation of EDL's protective and voltage regulation equipment.
- **EDL System Overcurrent Devices** – To maintain proper operation of EDL's overcurrent protection equipment.
- **EDL System Operating Efficiency** – To ensure operation at appropriate power factors and minimize system losses.

[1] "Acceptable" power quality is power delivered to customers that does not impair operation of the customers' equipment or cause visible light flickering due to voltage fluctuations under normal operating conditions. One element of power quality is voltage flicker, which is a function of the magnitude of voltage fluctuation and the frequency at which the fluctuation occurs. Voltage flicker is described in Section 4.n. of these standards.

These technical interconnection standards are based on the requirements of IEEE 1547-2018 *Standard for Interconnecting Distributed Resources with Electric Power Systems* (or latest version).[2] EDL intends to maintain consistency between its requirements for interconnection of distributed PV generating facilities and IEEE interconnection standards to the extent feasible, considering the specific design and operating requirements of EDL's electric power system. Except as otherwise provided herein, EDL will evaluate all future revisions to IEEE standards directly related to interconnection of distributed generating facilities, if any, and update these Distributed Solar Photovoltaic Generating Facility Interconnection Standards (DPV Interconnection Standards) accordingly.

Any use of an Advanced Inverter shall utilize IEEE 1547.1-2020 and UL1741 – Supplement SA (or latest applicable version) to certify the Advanced Inverter functions specified in Section 4 of these DPV Interconnection Standards.

Customers are encouraged to review and discuss these technical DPV Interconnection Standards with EDL before proceeding with their design and procurement of generating facility equipment.

[2] IEEE – Institute of Electrical and Electronic Engineers. The IEEE standards or products referred to herein are trademarks owned by The Institute of Electrical and Electronics Engineers, Incorporated. IEEE publications are available from the Institute of Electrical and Electronics Engineers (http://standards.ieee.org/). IEEE 1547-2018 does not address planning, designing, operating, or maintaining the area electric power system (IEEE 1547-2018, Section 1.4).

1. Definitions

For the purposes of these DPV Interconnection Standards, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in these standards.

a. Active Anti-Islanding Scheme: Equipment or control schemes installed with the Generating Facility that prevents the formation of an unintended island.

b. Advanced Inverter: A Generating Facility's Inverter that performs functions that when activated, can autonomously contribute to grid support by providing dynamic reactive/real power support, voltage and frequency Ride-Through, ramp rate controls, communication systems with ability to accept external commands, and other functions.

c. Cease to Energize: Cessation of active current exchange related to the active power production of the Advanced Inverter with the Distribution System in not more than the maximum specified time. Cease to Energize does not necessarily imply galvanic separation or a trip of the grid connected Advanced Inverter.

d. Clearing Time: The time between the abnormal voltage being applied and the Generating Facility ceasing to energize the Distribution System.

e. Continuous Operation: The Generating Facility operates indefinitely without tripping. Any functions that protect the Advanced Inverter from damage may operate as needed.

f. Dedicated Transformer: A transformer that provides electrical service to a single customer.

g. Distribution System: All electrical wires, equipment, and other facilities at the distribution voltage levels (such as 22kV and 230V) owned or provided by EDL, through which EDL provides electrical service to its customers.

h. Electric Power System: Equipment or facilities that deliver electric power to a load (i.e., EDL's Distribution System and/or Transmission System).

i. Facility Equipment List: Identifies equipment, space, and/or data at the Generating Facility location to be provided by the customer for use in conjunction with EDL's Interconnection Facilities. The Facility Equipment List will be included in any interconnection agreement entered between EDL and the customer.

j. Generating Facility: Customer or EDL-owned PV Inverter based generation that is interconnected to the Distribution System.

k. Initial Technical Review: The review by EDL following receipt of an

Interconnection Application to determine the following: a) if the Generating Facility qualifies for Simplified Interconnection; or b) if the Generating Facility can be made to qualify for interconnection with a Supplemental Review determining additional requirements, if any.

l. Interconnection Application: Approved application submitted to EDL for interconnection of a Generating Facility.

m. Interconnection Facilities: The electrical wires, switches and related equipment that are required in addition to the facilities required to provide electric distribution service to a customer to allow interconnection. Interconnection Facilities may be located on either side of the Point of Interconnection as appropriate to their purpose and design. Interconnection Facilities may be integral to a Generating Facility or provided separately.

n. Interconnection Requirements Study (or "IRS"): A study to establish the requirements for interconnection of a Generating Facility with EDL's Distribution System.

o. Inverter: A machine, device, or system that changes direct-current power to alternating-current power.

p. Lao PDR Laws: Any legislation, statute, act, decree, rule, order, treaty, regulation or announcement or any other law (excluding the Technical Standards), or any interpretation thereof, which has been enacted, issued or promulgated by the Government of the Lao PDR.

q. Line Section: The portion of EDL's Distribution System connected to a customer bounded by sectionalizing devices, or the end of a distribution line. Where a radial distribution circuit does not have sectionalizing devices, the whole circuit is considered one Line Section.

r. Mandatory Operation: The Advanced Inverter shall continue to exchange active current and reactive current with the Electric Power System as prescribed, notwithstanding disturbances of the Electric Power System voltage or frequency having magnitude and duration severity within defined limits.

s. Momentary Cessation: Temporarily Cease to Energize in response to a voltage or frequency disturbance, with the capability of immediate restore output of operation when the Electric Power System voltage and frequency return to within defined ranges.

t. Network System: An electrical system in which two or more Distribution System feeder sources are electrically tied together on the primary or secondary voltage level to form one power source for one or more customers. The Network System is designed to provide higher reliability for customers connected to it.

u. Parallel Operation: The operation of a Generating Facility, while interconnected, such that customer load can be fed by the Generating Facility and Distribution System simultaneously.

v. Permissive Operation: In response to an abnormal excursion, the Generating Facility is allowed, but not required, to operate at any current level.

w. Point of Interconnection: The point at which the Distribution System and the customer interface occurs.

x. P_predisturbance (“P_{pre}”): The active power output level of the Advanced Inverter immediately prior to the disturbance, in p.u. of the Advanced Inverter rating. The P_{pre} mode is used in the frequency-watt response in Section 4.h.(ii), where the response depends on the P_{pre} value just prior to the disturbance.

y. P_rated (“P_{rated}”): The rated active power, in p.u. of the Advanced Inverter rating (i.e., 1.0 p.u.). The P_{rated} mode is used in the volt-wat response in Section 4.g.(iv), where the response is based on the P_{rated} value of the Advance Inverter.

z. Response Time or Open Loop Response Time: The time duration between a control signal input step change (reference value or system quantity) and the point in time when the output reaches 90% of its final change (before an overshoot). For example, in volt-watt mode, the Response Time is the time from a change in voltage until the corresponding change in Advanced Inverter output power.

aa. Return to Service: The criteria required for and behavior of the Advanced Inverter as it re-energizes the Electric Power System following an abnormal excursion resulting in a trip, Cease to Energize, or Momentary Cessation operation.

bb. Ride-Through: The ability to withstand voltage or frequency excursions outside defined limits without tripping or malfunctioning. While the Advanced Inverter is in Ride-Through state, the Source Requirements Document may require particular action such as Momentary Cessation or Mandatory Operation.

cc. Simplified Interconnection: Interconnection that passes the Initial Technical Review without a need for a Supplemental Review.

dd. Source Requirements Document: A document that includes the required operational functions, operating parameters including limits and Response Times for Advanced Inverter testing.

ee. Supervisory Control: Remote monitoring and/or control of a Generating Facility’s power output and interrupting device status by means of a communication channel that is acceptable to the utility.

ff. Supplemental Review: A process wherein EDL further reviews an Interconnection Application that does not pass the Initial Technical Review screens. The intent of the Supplemental Review is to provide a slightly more detailed review of only the conditions that cause the Generating Facility to fail the Initial Technical Review. The Supplemental Review may result in one of the following: a) approval of interconnection; b) approval of interconnection with additional requirements; or c) cost and schedule for an IRS.

gg. Technical Standards:

(i) the Law on Electricity (№ 19/NA, 09 May 2017) (the “Electricity Law”), as may be amended from time to time;

(ii) the Lao Electric Power Technical Standards (№ 052/MOIH, 12 February 2004) (the “LEPTS”), where relevant;

(iii) the Guideline on Operating and Managing Lao Electric Power Technical Standards and Safety Rules for Operation (“LEPTS Guidelines”), where relevant; and

(iv) provisions set forth in these DPV Interconnection Standards.

hh. Technical System Size: Technical System Size as used herein applies to photovoltaic Inverter-based generation, including those paired with energy storage systems. Technical System Size refers to the maximum possible simultaneous generation (including discharge of energy storage systems) of the Generating Facility, and is calculated as the lesser of the sum of all Inverter strings of the aggregate system or the maximum amount of export as permitted by the existence of an on-site limiting element that caps the amount of the Generating Facility’s export at the Point of Interconnection. Each Inverter string is calculated as the sum of all simultaneous kWdc per Inverter string or the Inverter kWac per Inverter string, whichever is less. Technical System Size is used as part of the technical review process as described herein.

ii. Transmission System: All electrical wires, equipment, and other facilities at the transmission voltage levels (such as 230kV or 115kV) owned or provided by EDL, through which the utility provides electrical service to its customers.

jj. Unintended Islanding: A condition in which one or more Generating Facilities deliver power to a utility customer or customers using a portion of the Distribution System that is electrically isolated from the remainder of the Electric Power System in a manner that is not intended. Unintended Islanding may occur following an unanticipated loss of a portion of the Distribution System.

2. General Interconnection Guidelines

a. Compliance with Laws and Codes:
The Generating Facility, protection, interconnection equipment, design, design drawings, construction and operation shall comply with all applicable Lao PDR Laws, Technical Standards and applicable accepted international engineering practices including accepted IEC, IEEE and UL standards, construction and safety codes.

b. Interpretation:

(i) The interpretation and performance of these DPV Interconnection Standards shall be in accordance with and governed by Lao PDR Laws.

(ii) If any section or clause of these DPV Interconnection Standards is ruled invalid by a court of competent jurisdiction, it shall not affect the remainder of the DPV Interconnection Standards if it can be construed to affect its essential purpose without the invalid section or clause.

(iii) References to Lao PDR Laws, Technical Standards or applicable accepted international engineering practices include references to those Lao PDR Laws, Technical Standards or applicable accepted practices as they may change or be amended from time to time. To the extent that an applicable accepted practice conflicts with any Lao PDR Laws and/or Technical Standards, the latter shall control.

(iv) References to sections and clauses are references to sections and clauses in these DPV Interconnection Standards, unless the context otherwise requires.

(v) The singular includes the plural and vice versa.

c. Notification for Supplemental Review:
determination that Supplemental Review will be required based on the results of the Initial Technical Review, EDL shall notify the customer in writing within fifteen (15) business days, or such other period as is mutually agreed upon in writing between EDL and the customer, following the Initial Technical Review of any Supplemental Review required and the reasons for such review.

d. Export of Power:
A Generating Facility intending to export power to the EDL Distribution System that will cause a reversal of power flow at any voltage regulation device that is not bi-directional may require Supplemental Review or an IRS that will be completed by EDL to evaluate the impacts on equipment ratings and protective relay settings. If an IRS is required, analyses such as a feeder load flow, dynamic stability analysis, transient overvoltage, short circuit and relay coordination may need to be performed in order to evaluate the impacts of the

export of power on equipment ratings and protective relay settings. Generating Facilities that export power to the Distribution System may change the direction of power flow on the Distribution System. The magnitude of the change in power flow will be a function of the aggregate amount of export power on a feeder, the location of the generating facilities exporting power on a feeder, the feeder load, and the location of loads on a feeder. The need for an IRS will depend on these factors.

e. Distribution System Feeder Penetration:
As the penetration of generating capacity increases on a Distribution System feeder (e.g., 22 kV and 230 V circuits), there is increased risk of vol tage regulation problems, adverse interactions with the utility's protection system, and Unintended Islanding. Therefore, Supplemental Review to examine the risk of voltage regulation problems, protection malfunction from reverse power flow, and Unintended Islanding may be required when the aggregate generating Technical Capacity per distribution Line Section exceeds 15% of the annual peak KVA load of the Line Section. If an IRS is required, analyses such as a feeder load flow may need to be performed in order to evaluate the risk of voltage regulation problems, protection malfunction from reverse power flow and Unintended Islanding. The need for an IRS will be identified by EDL during Supplemental Review.

To avoid excessive unbalanced loading on an EDL Distribution System Line Section or equipment, interconnection of a single-phase Generating Facility with a capacity greater than 5kW shall be reviewed by EDL in its Initial Technical Review. Based upon the results of the Initial Technical Review, EDL may determine that Supplemental Review is required.

f. Network Interconnection:
Connection of a Generating Facility on utility distribution Network Systems shall be reviewed by EDL in its Initial Technical Review of the impact of the Generating Facility on EDL's Distribution System. Based upon the results of the Initial Technical Review, EDL may determine that Supplemental Review of the network interconnection is necessary.

g. Short Circuit Contribution Ratio:
A Generating Facility's short circuit current contribution to the EDL Distribution System and its distribution feeders can affect the operation of existing utility protective devices. A good indicator of the potential impact of a Generating Facility's short circuit contribution is the Short Circuit Contribution Ratio ("SCCR"). The SCCR evaluates the short circuit current contribution of the Generating Facility in two ways. First, the SCCR is evaluated as the ratio of the Generating Facility short circuit contribution to the short circuit contribution of the Electric Power System for a three-phase fault at the high voltage side of the customer or utility transformer connecting the Generating Facility to the Distribution System (aggregate SCCR must be less than or equal to 10%). Second, it compares the Generating Facility short circuit

current to the interrupt rating of the customer's service panel to ensure that the customer's equipment will not be overloaded.

h. Integration with Utility Grounding and Ground System Protection:
The grounding scheme and the ground fault protection of the Generating Facility shall be coordinated with the Electric Power System to ensure a ground fault is cleared properly. Any ground faults detected by the Electric Power System's protection scheme (for faults on the Distribution System feeder between the substation and the Generating Facility) must also be detected by the protection scheme of the Generating Facility. For a single line to ground fault on the connecting Distribution System feeder, the Generating Facility's ground fault protection must be sufficient to prevent damage to the Electric Power System and other customer equipment due to overvoltage caused by ferroresonance, displaced neutral, or self-excitation. The Generating Facility must disconnect before the Distribution System feeder breaker recloses automatically.

i. Transformer Winding Configuration:
The transformer winding configuration of the customer or EDL distribution transformer serving the Generating Facility shall be reviewed by EDL in its Initial Technical Review to determine the potential impact to the Electric Power System and Generating Facility, and subsequent interconnection requirements. Based upon the results of a line configuration screen of the Initial Technical Review, EDL may determine that Supplemental Review of the transformer winding configuration is necessary.

j. Interconnection of Generating Facility:
Once a Generating Facility has been interconnected to EDL's Distribution System, EDL reserves the right to require the installation of, or modifications to, equipment determined by the utility to be necessary to facilitate the delivery of reliable electric service to its customers, provided that the costs associated with such post interconnection installations or modifications shall be paid by EDL or through other approved mechanisms.

3. Generating Facility Design Requirements

a. Isolation Device:
The customer shall furnish and install a manual isolation device that has a visible break to isolate their Generating Facility from the Distribution System. The isolation device shall either be a disconnect switch or a breaker with rack-out capability. The device must be accessible to EDL personnel and be capable of being locked by utility personnel in the open position. For generating facilities that do not have a circuit breaker or interrupting device, the isolation device must be capable of interrupting load. An existing service disconnect device may be used if it meets these requirements. A label indicating "Customer Generating Facility" shall be attached to the Generating Facility manual isolation device.

b. Interrupting Device:
Applicable circuit breakers or interrupting devices at the Generating Facility must be capable of interrupting the maximum available fault current at the site, including any contribution from the Generating Facility. For a Generating Facility that is greater than 10kW, the interrupting device must be accessible to EDL personnel at all times.

c. Supervisory Control:
Supervisory Control may be required for a Generating Facility with an aggregate capacity greater than 250kW, but shall not be required for a Generating Facility with an aggregate capacity of 250kW or less.

Supervisory Control shall include monitoring of: (i) gross generation by the Generating Facility; (ii) feedback of Watts, Vars, Watt-Hours, current and voltage; (iii) Vars furnished by the utility; and (iv) status of the interrupting device. In addition, the Supervisory Control will allow EDL to trip the interrupting device during emergency conditions.1 Monitoring will be performed by EDL system dispatchers or operators at EDL's control center.

d. Equipment Testing:
The Generating Facility shall provide to EDL the manufacturer's brochures/instruction manuals and technical specifications of their proposed

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[1] Emergency conditions refer to the need for immediate action in response to a situation that has caused injury, loss of life or property damage. Emergency conditions include, but are not limited to:

- A system emergency or forced outage;
- A potential hazard to EDL personnel or the general public;
- A hazardous condition relating to the generating facility;
- The generating facility is interfering with EDL's equipment or equipment belonging to other customers (including non-utility generating equipment);
- The generating facility's protective devices have been tampered with by the customer and/or owner and/or operator of the generating facility; or
- A need for immediate action in response to a situation that has caused (or has the potential to cause) injury, loss of life or property damage.

Generating Facility equipment, and test reports for evaluation by EDL.

In addition, verification tests of customer-owned equipment shall be performed on-site by customer to verify protective settings and functionality to ensure that the equipment will not adversely affect the Distribution System and that it will cease providing power to the system under abnormal conditions. A verification test shall be performed upon initial Parallel Operation of the Generating Facility, or whenever interface hardware or software is changed that can affect the protective functions. These tests shall be done by a qualified individual (hired or employed by the customer) in accordance with the manufacturer's recommended test procedure and in concurrence with EDL. Qualified individuals include professional engineers, factory trained and certified technicians, and licensed electricians with experience in testing protective equipment. To ensure that verification tests of customer-owned equipment are performed correctly, EDL may request to witness the tests and receive written certification of the results from the qualified individual. The customer must inform EDL in writing of proposed changes in the customer's interconnection hardware or software that are related to the performance, operation, or timing of the protective functions not later than fifteen (15) business days prior to implementation of such changes. Upon receiving notice of such proposed changes from the customer, EDL must notify the customer in writing of any concerns regarding the proposed changes within fifteen (15) business days, in which case the changes shall not be implemented until the customer and EDL resolve the concerns to their mutual satisfaction and document the resolution in writing.

All interconnection-related protective functions and transfer trip schemes, if applicable, shall be periodically tested at intervals specified by the manufacturer, or in accordance with industry practice. (When the interval is not specified by the manufacturer or by EDL, protective functions should be tested every year.) The customer shall submit or make available for inspection by EDL, test reports of such testing. Periodic testing conforming to the utility test intervals for the particular Line Section can be specified by EDL under special circumstances (e.g., where the Generating Facility is connected to a Line Section that has experienced a high frequency of outages due to natural or unnatural causes such as in coastal areas where there are high winds). EDL will determine whether special circumstances exist, and must inform the customer in writing of any such determination and the reasons for that determination. A system that depends upon a battery for trip power shall be checked and logged once per month for proper voltage, or monitored continuously.

4. Generating Facility Operating Requirements

This Section 4 (Generating Facility Operating Requirements) shall apply for interconnection of Generating Facilities, which shall be certified to IEEE 1547.1-2020 with UL-1741 Supplement SA *Standard for Grid Support Utility Interactive Inverters and Converters* using the applicable EDL Source Requirements Document at the time of the Interconnection Application.

The Inverter requirements are intended to be consistent with IEEE 1547-2018 *Standard for Interconnecting Distributed Resources with Electric Power Systems*. In the event of conflict between these DPV Interconnection Standards and IEEE 1547-2018, these standards shall take precedence.

An Inverter interfaced Generating Facility that is to be installed in parallel with the Distribution System must employ a non-islanding synchronous Inverter. The Inverter design shall comply with the requirements of IEEE 1547-2018 and UL 1741 Supplement SA standards (or latest versions) and be certified to have anti-islanding protection such that the synchronous Inverter will automatically disconnect upon an Electric Power System interruption.

Self-commutated Inverters of the utility-interactive type shall synchronize to the utility. Inverters capable of stand-alone operation shall not attempt to control the voltage while operating in parallel with the Distribution System, except through volt-var and volt-watt control as specified below. Line-commutated, thyristor-based Inverters are not recommended and will require Supplemental Review or an IRS to determine harmonic and reactive power requirements. All interconnected Inverters shall comply with the harmonic current limits of IEEE Std 1547-2018.

Prevention of Interference
The Generating Facility shall not operate Advanced Inverters that superimpose a voltage or current upon the Distribution System that interferes with EDL operations, service to utility customers, or communication facilities. If such interference occurs, customer must diligently pursue and take corrective action at its own expense after being given notice and reasonable time to do so by EDL. If customer does not take corrective action in a timely manner, or continues to operate the Generating Facility causing interference without restriction or limit, EDL may, without liability, disconnect the Generating Facility from the Distribution System, in accordance with Section 4.b below. To eliminate undesirable interference caused by its operation, each Advanced Inverter shall meet the following criteria:

a. Disconnection of Generating Facility for Utility Reasons:
Upon providing reasonable notice (generally not to be less than ten (10) business days for scheduled work), EDL may require the Generating Facility to temporarily disconnect from the Distribution System when necessary for EDL to construct, install, maintain, repair, replace, remove, investigate, test, or inspect any of its equipment or other utility customer's equipment, or any part of its Electric Power System. The Generating Facility shall not energize a

de-energized utility line or Line Section under any circumstances, but may operate isolated from the EDL Distribution System with an open tie point in accordance with Section 4.i below.

If the utility determines that such disconnection is necessary because of unexpected Electric Power System emergencies, forced outages, operating conditions on the Electric Power System, or compliance with good engineering practices as determined by EDL's engineers and/or operations personnel, EDL will immediately attempt to notify, in person, by telephone, by electronic mail, or by facsimile, the customer's designated representatives of the need to disconnect the customer's Generating Facility. Unless the emergency condition requires immediate disconnection as determined by EDL, EDL shall allow sufficient time for the Generating Facility operator to manually disconnect the generator. (As stated in Section 4.b below, there are circumstances where EDL may disconnect the Generating Facility without prior notice to the customer.)

Following the completion of work and/or rectification of the emergency conditions by the utility, EDL shall reset the customer's isolation device, if open, as soon as practicable and shall provide, within fifteen (15) business days or such other period as is mutually agreed upon in writing by EDL and the customer, written documentation of the occurrence and nature of EDL's work and/or emergency condition, and the disconnection of the customer's Generating Facility.

EDL shall take reasonable steps to minimize the number and duration of such disconnections. EDL may disconnect the customer from EDL's Distribution System for failure by the customer to disconnect their Generating Facility under this Section 4.a, until such time that the utility work or emergency condition has been corrected and the normal system condition has been restored.

The Generating Facility may be disconnected by EDL at the Generating Facility location or remotely by Supervisory Control, if available.

b. Personnel and System Safety:

EDL may disconnect the Generating Facility from EDL's Distribution System, without prior notice to the customer: (a) to eliminate conditions that constitute a potential hazard to EDL's personnel or the general public; (b) if pre-emergency[2] or emergency conditions exist on EDL's Electric Power System; (c) if a hazardous condition relating to the Generating Facility is observed by EDL's inspection; (d) if the Generating Facility interferes with EDL's equipment or equipment belonging to other utility customers (including non-utility generating equipment); or (e) if the customer or a party with whom the customer has

[2] Pre-emergency conditions refer to the need for immediate action in response to a situation that has the potential to cause injury, loss of life, or property damage.

contracted for ownership and/or operation of the Generating Facility has tampered with any protective device. The Generating Facility shall remain disconnected until such time as EDL is satisfied that the endangering condition(s) has been corrected, and EDL shall not be obligated to allow Parallel Operation of the Generating Facility during such period. If EDL disconnects the Generating Facility under this Section 4.b, it shall as soon as practicable notify the customer in person, by telephone, by electronic mail, or by facsimile and provide the reason(s) why the Generating Facility was disconnected from EDL's Distribution System. Following the rectification of the endangering conditions, EDL shall provide, within ten (10) business days or such other period as is mutually agreed upon in writing by EDL and the customer, written documentation of the occurrence and nature of the endangering conditions, and the disconnection of the customer's Generating Facility.

The Generating Facility may be disconnected by EDL at the Generating Facility location or remotely by Supervisory Control, if available.

c. Synchronization:
Upon connection, the Generating Facility shall synchronize with the Distribution System. Synchronization means that at the Point of Interconnection, the frequency difference shall be less than 0.2 Hz from rated frequency, the voltage difference shall be less than 5% of nominal voltage, and the phase angle difference shall be less than 10 degrees.

d. Voltage Regulation:
As specified in the sections on volt-var and volt-watt below, the Advanced Inverter shall actively regulate the voltage at the Point of Interconnection while in Parallel Operation with the Distribution System. The Advanced Inverter shall not cause the service voltage at other customers to go outside the requirements of ANSI C84.1-2016, Range A (IEEE 1547-4.1.1).

e. Unintended Islanding:
For public and EDL personnel safety and to prevent possible damage to utility customer equipment, the Generating Facility shall be equipped with protective equipment designed to prevent the Generating Facility from being connected in parallel with a de-energized Line Section of the Distribution System. The Generating Facility must automatically disconnect from the Distribution System upon loss of utility source, and remain disconnected until the voltage and frequency have stabilized (see Section 4.j below). Protective device requirements, such as direct transfer trip, grounding bank, or Active Anti-Islanding Scheme, shall be determined by EDL based upon the results of the Initial Technical Review and/or Supplemental Review.

f. Disconnection for Faults:
The Generating Facility shall be equipped with protective equipment designed to automatically disconnect the Generating Facility from the Distribution System for faults on the utility distribution circuit to which it is connected, and

remain disconnected until the voltage and frequency have stabilized (see Section 4.j below).

g. Voltage Disturbances:
The voltage ranges in Table 4-1 below define protective trip limits for the protective function and are not intended to define or imply a voltage regulation function. A Generating Facility shall Cease to Energize the Distribution System within the prescribed trip time whenever the voltage at the Point of Interconnection deviates from the allowable voltage operating range. The protective function shall detect and respond to voltage on all phases to which the Generating Facility is connected.

(i) Advanced Inverters: Advanced Inverters shall be capable of operating within the voltage range(s) as specified in Table 4-1. The trip settings at the generator terminals may be selected in a manner that minimizes nuisance tripping in accordance with Table 4-1 to compensate for voltage drop between the generator terminals and the Point of Interconnection. Voltage may be detected at either the generator terminals or the Point of Interconnection. However, the voltage at the Point of Interconnection, with the Generating Facility on-line, shall stay within the range of +/- 5% of nominal under normal operating conditions.

(ii) Voltage Disturbances: Whenever the Distribution System voltage at the Point of Interconnection varies from and remains outside the normal operating high and normal operating low region voltage for the predetermined parameters set forth in Table 4-1, the Advanced Inverter's protective functions shall cause the Advanced Inverter to Cease to Energize the Distribution System. Unless provided alternate settings by EDL, an Inverter-based Generating Facility must comply with the standard voltage Ride-Through and trip settings specified in Table 4-1:

(1) The Advanced Inverter shall stay connected to the Distribution System while the grid remains within the "Ride-Through Until" voltage-time range and must operate in accordance with the "Operating Mode" specified for each "Operating Region."

(2) In the Continuous Operation region, the Advanced Inverter shall reduce power output as a function of voltage, in accordance with Section 4.g(iv) (Volt-Watt) below.

(3) Different settings than those specified in Table 4-1, Section 4.g(iii) Return to Service (Table 4-2 below), and Section 4.g(iv) Volt-Watt (Table 4-3 below) may be specified by EDL.

Table 4-1: Voltage Ride-Through

Operating Region	Voltage at Point of Interconnection (% of Nominal Voltage)	Operating Mode	Ride-Through Until (sec)	Default Maximum Trip Time (sec)
OV2	V > 120	Cease to Energize	N/A	0.2[(1)]
OV1	120 ≥ V > 110	Mandatory Operation	0.92	1
CO	110 ≥ V > 100	Continuous Operation (Volt-Watt)	N/A	N/A
CO	100 > V ≥ 88	Continuous Operation	N/A	N/A
UV1	88 > V ≥ 70	Mandatory Operation	20	21
UV2	70 > V ≥ 50	Mandatory Operation	10 - 20[(2)]	11 - 21[(2)]
UV3	50 > V	Momentary Cessation	N/A	2

(1) Must trip time under steady state condition. Inverters shall also meet the requirements of Section 4.t. Limiting Over Voltage Contribution. Ride-Through shall not inhibit the Limiting Over Voltage Contribution requirements.

(2) Maximum trip time may be adjusted within this range at manufacturer's discretion.

(iii) Return to Service: At initial startup or when returning to service or after a power system disturbance that caused an Advanced Inverter to trip, the Advanced Inverter shall Return to Service in accordance with EDL's Source Requirements Document. The default values for the Return to Service function are indicated in Table 4-2.

Table 4-2: Return to Service Settings

Return to Service	Default Value
Voltage (% of nominal voltage)	88% – 110%
Reconnection time delay (sec)	300 - 600[(1)]

(1) Time delay settings may be adjusted within this range at manufacturer's discretion

(iv) Volt-Watt: The Advanced Inverter shall be certified to perform the volt-watt function in accordance with the EDL's Source Requirements Document.

In this mode, the Advanced Inverter shall actively control the active power output as a function of voltage following a volt-watt piecewise linear characteristic in accordance with the parameters specified in the Source Requirements Document.

If activated, the volt-watt function shall remain active while any of the other voltage and reactive power modes is activated and operate in P_{rated} mode as shown in Figure 4-1.

The volt-watt function shall be activated if required by EDL. The Default Values shall be as specified in Table 4-3 and illustrated in Figure 4-1 below.

Table 4-3: Volt-Watt Settings

Parameters[(1)]	**Default Value**
V_1	1.06 of Nominal Voltage (V_N), (e.g. 230 Volt)
P_1	P_{rated} is the rated active power output of the Advanced Inverter.
V_2	1.1 of V_N
P_2	Advanced Inverter's Minimum Active Power (P_{min}) (for Advanced Inverters that can only inject active power, P_{min} should approach 0)
Response Time	10 seconds

(1) See IEEE 1547-2018 for parameter definitions.

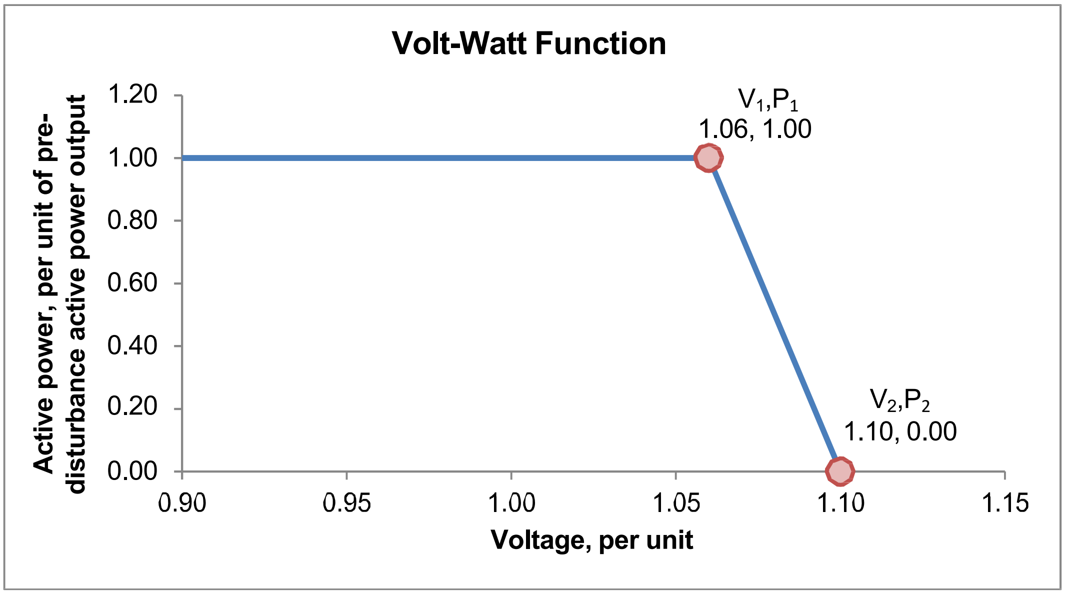

Figure 4-1: Volt-Watt Function per Table 4-3.

h. Frequency Disturbances:
EDL controls system frequency, and the Generating Facility shall operate in synchronism with the utility Distribution System. Whenever the Electric Power System frequency at the Point of Interconnection varies from and remains outside normal (nominally 50 Hz) by the predetermined amounts set forth in Table 4-4 below, the Generating Facility's protective functions shall Cease to Energize the utility Distribution System within the stated maximum trip time. Unless provided alternate settings by EDL, the Generating Facility must comply with the standard frequency Ride-Through and trip settings specified in Table 4-4.

(i) Frequency Ride-Through Requirements: Advanced Inverter based systems shall remain connected to the Distribution System while the grid is within the frequency-time range indicated in Table 4-4, and shall Cease to Energize and trip from the electric grid during a high or low frequency event that is outside of that frequency-time range. These values provide default interconnection system response to abnormal frequency conditions. The Advanced Inverter shall disconnect by the Default Maximum Trip Time in Table 4-4. The Advanced Inverter shall reduce real power output as a function of frequency in accordance with Section 4.h(ii) Frequency-Watt Settings (Table 4-4). Electrical islands and microgrids may need different default frequency settings.

Table 4-4: Frequency Ride-Through and Trip Settings

Operating Region[(1)]	Frequency at Point of Interconnection	Operating Mode	Ride Through Until (sec)	Default Maximum Trip Time (sec)
OF2	f > 52.0	Permissive Operation	None	1
OF1	52.0 ≥ f > 51.0	Mandatory Operation (Freq-Watt)	5	21
CO	51.0 ≥ f > 50.0	Continuous Operation (Freq-Watt)	Indefinite	N/A
CO	50.0 > f ≥ 49.0	Continuous Operation	Indefinite	N/A
UF1	49.0 > f ≥ 47.0	Mandatory Operation	5	21
UF2	47.0 > f	Permissive Operation	None	1

(1) OF – Over Frequency, CO – Continuous Operation, UF – Under Frequency.

(ii) Frequency-Watt: The Advanced Inverter shall be certified to perform the Frequency-Watt function in accordance with EDL's Source Requirements Document. In this mode, the Advanced Inverter shall modulate active power when the frequency at the Point of Interconnection is outside the Frequency-Watt deadband in accordance with the parameters specified in the Source Requirements Document.

The power modulation shall be on a percentage basis of the available pre-disturbance (P_{pre}) active power existing at the time the frequency is outside the specified deadband. Example curves for 1.0 p.u., 0.75 p.u. and 0.5 p.u. P_{pre} are shown in Figure 4-2.

Upon mandatory activation of the Frequency-Watt function, the Default Values shall be as indicated in Table 4-5 and illustrated in Figure 4-2 below.

Table 4-5: Frequency-Watt Settings

Parameter[1]	**Default Value**
dbOF (Hz)	0.03
kOF	0.033
Response time (sec)	0.5[2]

[1] See IEEE 1547-2018 for parameter definitions.

[2] On an interim basis, the Frequency-Watt function may be activated with a Response Time between 0.5 and 3 seconds consistent with the Open-Loop Response Times specified in EDL's Source Requirements Document. A Response Time of 0.5 seconds is the preferred Default Value.

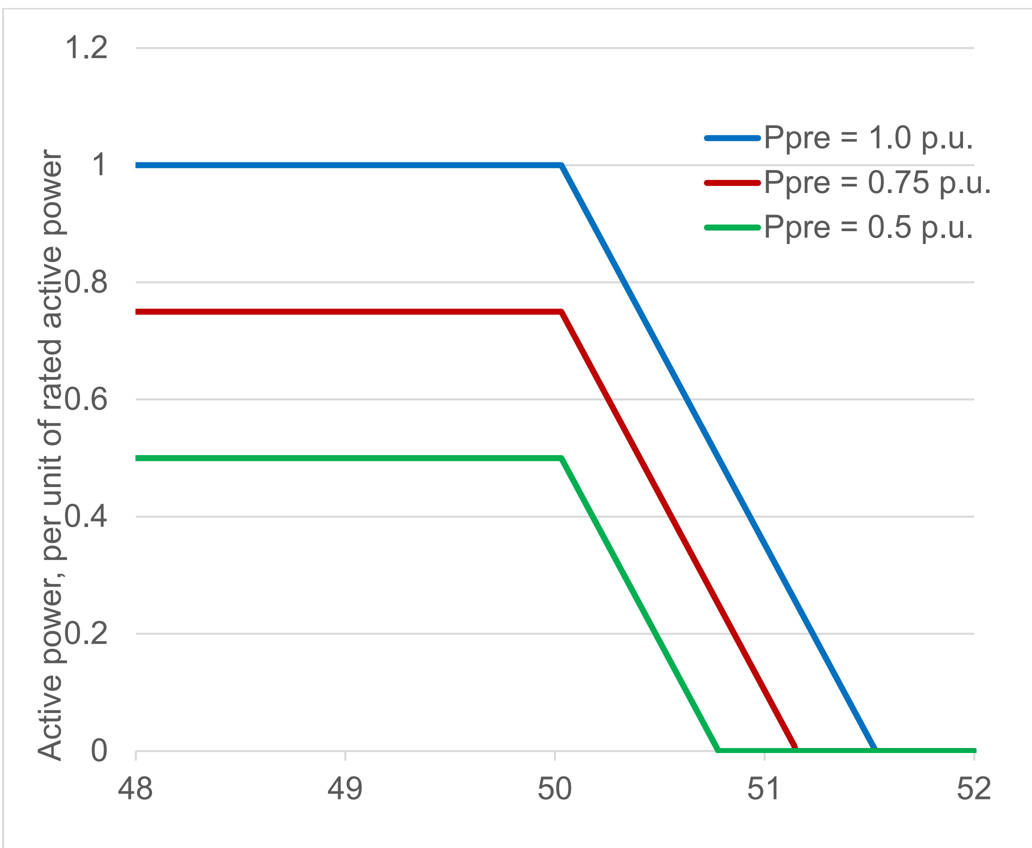

Figure 4-2: Frequency-Watt settings per Table 4-5.

i. Inadvertent Energization, Operation During Utility System Outage:
The Generating Facility shall not energize a de-energized Line Segment or other EDL equipment for any reason. The Generating Facility may be operated isolated from the EDL Distribution System during a utility outage or Electric Power System emergency only with an open tie breaker or disconnect device that isolates the Generating Facility from the EDL Distribution System. This shall generally be done through manual opening and lockout of the customer's service breaker or isolation device (required under Section 3.c above) by EDL personnel prior to starting the Generating Facility.

Where customers desire the ability to manually or automatically isolate their Generating Facility from the utility system by themselves, EDL will consider alternative designs proposed by the customer that will prevent inadvertent energization of a de-energized Line Segment of other EDL equipment. Such alternative design proposals shall be reviewed and approved in writing by EDL prior to implementation. EDL shall not unreasonably withhold such approval. Upon implementation of an alternative design approved by EDL, the customer may isolate itself from the Distribution System during a utility outage and operate its Generating Facility. Customers' alternative designs may, subject to review and approval by EDL, enable customers to manually or automatically reconnect back to the Distribution System upon restoration of utility system power, provided that EDL has not locked out the customers' service as described below and subject to the delay requirements specified in Section 4.j below.

In certain situations, including any time that EDL personnel will be performing work on the Distribution System serving the Point of Interconnection, EDL may determine the need to actively verify the open tie point, and to install an EDL lock to ensure the safety of EDL personnel. The customer shall provide access to the isolation device required under Section 3.c above for EDL personnel to visually confirm the open tie point and install an EDL lock if necessary. Following restoration of grid power or rectification of the emergency condition, EDL personnel shall, as soon as practicable, remove the EDL lock to allow reconnection of the Generating Facility with the Distribution System.

Generators that are not interconnected to EDL's Distribution System at any time and which are therefore not covered under an interconnection agreement may be operated by customer at their discretion.

j. Required Delay on Reconnection:
The Generating Facility shall be equipped with automatic means to prevent reconnection of the Generating Facility with the Distribution System until the utility service voltage and frequency are within the normal operating ranges and stable for at least five (5) minutes, unless earlier directed by EDL.

k. Loss of Protection:
Failure of the Generating Facility interconnection protection equipment,

including loss of control power, shall result in the automatic disconnection of the Generating Facility from the Distribution System until such time that the interconnection protection equipment has been restored. Such failure shall initiate a signal to trip a Generating Facility circuit breaker or shut down an Inverter. In the case of failure of EDL-owned protection equipment, following the rectification of the loss of protection, EDL shall provide, within fifteen (15) business days or such other period as is mutually agreed upon in writing by EDL and the customer, written documentation of the occurrence, and the disconnection of the customer's Generating Facility.

l. Reclosing Coordination:
The Generating Facility shall be coordinated with the utility system reclosing devices, by disconnecting from the Distribution System before the first reclose attempt and remaining disconnected until the voltage and frequency have stabilized (see Section 4.j above).

m. Fixed Power Factor:
The Advanced Inverter shall be certified to be capable of performing the fixed power factor function in accordance with the EDL's Source Requirements Document. In this mode, the Advanced Inverter shall operate at a constant power factor. The target power factor shall be in accordance with the parameters specified in the Source Requirements Document. The power factor settings are allowed to be adjusted locally and/or remotely.

Customer-Generator shall provide adequate reactive power compensation on site to maintain the Advanced Inverter power factor at the default Power Factor setting at rated output (i.e., reactive power priority) or a utility specified power factor in accordance with the following requirements:

i) Default power factor setting: -0.95 absorbing (underexcited)

ii) Generating Facility is greater than 15 kW: Adjustable range 1.0 +/-0.15 (0.85 absorbing (underexcited) to 0.85 injecting (overexcited)) down to 20% rated power.

iii) Generating Facility is less than or equal to 15 kW: Adjustable range 1.0 +/- 0.10 (0.90 absorbing (underexcited) to 0.90 injecting (overexcited)) down to 20% rated power.

iv) The maximum Response Time to maintain constant power factor shall be ten (10) seconds or less.

n. Voltage Flicker:
Any voltage flicker at the Point of Interconnection caused by the Generating Facility shall not exceed the limits defined in IEEE Standard 1547-2018. This requirement is necessary to minimize the adverse voltage effects upon other

utility customers on the Distribution System.

o. Harmonics:
Harmonic current distortion at the Point of Interconnection caused by the Generating Facility shall not exceed the limits stated in IEEE Standard 1547-2018. The customer is responsible for the installation of any necessary controls or hardware to limit the current harmonics generated from their Generating Facility to levels defined in IEEE Standard 1547-2018.

p. Direct Current Injection:
The Generating Facility shall not inject DC current greater than 0.5% of the full rated output current into the Distribution System at the Point of Interconnection under either normal or abnormal operating conditions.

q. Protection from Electromagnetic Interference (Immunity Protection):
The influence of electromagnetic interference (EMI) shall not result in a change in state or miss-operation of the Generating Facility interconnection system.

r. Volt-Var Operations:
The Advanced Inverter shall be certified to perform the volt-var function in accordance with the Source Requirements Document. In this mode, the Advanced Inverter shall actively control its reactive power output as a function of the voltage following a volt-var piecewise linear characteristic in accordance with the parameters specified in the Source Requirements Document.

If activated, the volt-var function shall be a mutually exclusive mode of reactive power control.

By mutual agreement between the customer and EDL, the Advanced Inverter System may operate in larger power factor ranges, including in 4-quadrant operations for storage systems, with the implementation of additional anti-islanding protection as determined by EDL.

The Advanced Inverter shall provide dynamic reactive power compensation (volt-var operation) within the following constraints:

- The Advanced Inverter shall not cause the line voltage at the Point of Interconnection to go outside the requirements of the latest version of ANSI C84.1, Range A.

- The Advanced Inverter shall be set to prioritize reactive power over active power implementation. The Advanced Inverter shall be able to absorb reactive power in response to an increase in line voltage, and inject reactive power in response to a decrease in line voltage.

- The Advanced Inverter may produce active power up to the kVA rating provided that the Advanced Inverter remains capable at all times to absorb or inject reactive power, to the full extent of the reactive power capability defined in Table 4-6 below and in accordance with the reactive power capability in the Source Requirements Document. In other words, the Advanced Inverter may need to reduce active power to meet the demanded reactive power.

- The maximum reactive power provided to the system shall be as directed by EDL.

The default values for the volt-var function are indicated in Table 4-6 and illustrated in Figure 4-3 below.

Table 4-6: Volt-Var Settingsໃຫ້#

Parameters[(1)]	**Default Value**
V_{Ref}	Nominal Voltage (V_N) (e.g. 230 volts)
V_2	V_{Ref} – 0.03 of V_N
Q_2	0
V_3	V_{Ref} + 0.03 of V_N
Q_3	0
V_1	V_{Ref} – 0.06 of V_N
Q_1	44% of nameplate apparent power
V_4	V_{Ref} + 0.06 of V_N
Q_4	44% of nameplate apparent power
Response Time	10 seconds

1) See IEEE 1547-2018 for parameter definitions.

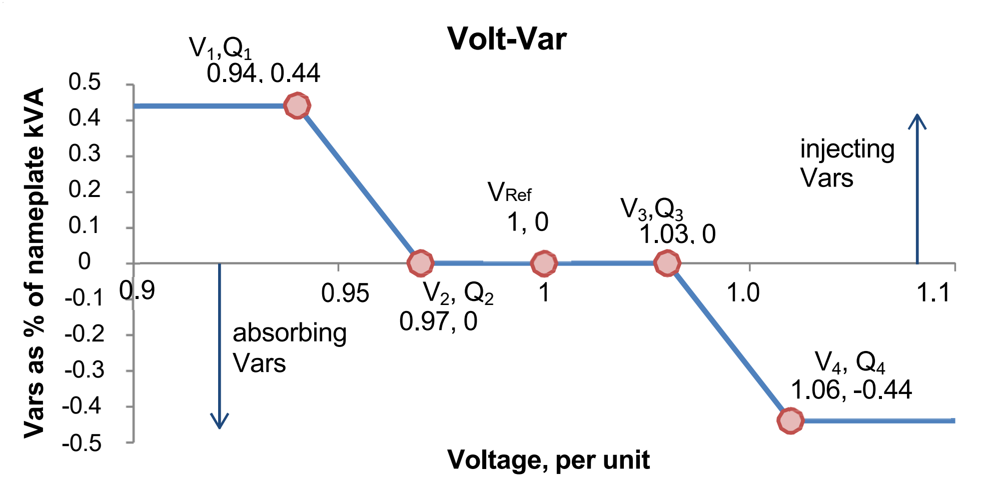

Figure 4-3: Volt-Var settings per Table 4-6.

s. Ramp Rate Requirements:
The Advanced Inverter is required to have the following ramp controls for at least the following two conditions. These functions may be established by multiple control functions or by one general ramp rate control function. Ramp rates are contingent upon sufficient energy available from the Advanced Inverter. Normal Ramp Rate and Soft-Start Ramp Rate shall operate in accordance with the Source Requirements Document. Default Values are indicated below.

- Normal Ramp Rate: The default value is 100% of maximum current output per second, with specific settings as mutually agreed by EDL and the customer.

- Soft-Start Ramp Rate: Upon starting to inject power into the Distribution System following a period of inactivity, trip, Return to Service, or a disconnection, the Advanced Inverter shall be able to control its rate of increase of power. The default value is 0.33% of maximum current per second, with specific settings as mutually agreed upon by EDL and the customer.

t. Limiting of Overvoltage Contribution:
The overvoltage protection equipment at the Generating Facility shall be certified to show that the Generating Facility will meet the requirements of the IEEE 1547-2018 *Limiting of Overvoltage Contribution* standard. The certification tests shall be conducted in accordance with the IEEE 1547.1-2020 load rejection overvoltage (LROV) test.

u. Remote Reconnect/Disconnect:
The Advanced Inverter shall be capable of receiving a remote command directly from EDL, or its agent(s), to connect or disconnect the Advanced Inverter from Parallel Operation pursuant to Sections 4.a and 4.b above.

v. Remote Configurability:
The Advanced Inverter shall be capable of receiving and implementing remote updates, including but not limited to: Advanced Inverter setting or parameter modifications, activation and deactivation of various Advanced Inverter functions, as required by EDL or its agent(s). The Advanced Inverter shall be capable of reporting current settings.

w. Default Activation States for Functions:
Unless otherwise provided by EDL, the default activation status for an Advanced Inverter shall be as follows:

- Anti-islanding – Mandatory Activation
- Transient Overvoltage – Mandatory Activation
- Low/High Voltage Ride-Through – Mandatory Activation
- Low/High Frequency Ride-Through – Mandatory Activation
- Frequency-Watt P_{pre} – Mandatory Activation
- Volt-Watt P_{rated} – Activation by Mutual Consent
- Volt-var – Mandatory Activation
- Normal and Soft-Start Ramp Rate – Mandatory Activation
- Fixed power factor – Mandatory Deactivation

These default activation states may be modified by mutual agreement between EDL and the customer.

5. Protection, Synchronizing, and Control Requirements

a. Protection Requirements:
The Generating Facility shall, at a minimum, provide adequate protective devices which include over/under voltage trip, over/under frequency trip, reverse power relay (for non-export generating facilities), and a means for automatically disconnecting the Generating Facility from the utility Distribution System whenever a protective device initiates a trip. Based upon the results of the Initial Technical Review and/or Supplemental Review by EDL, additional protective devices may be required. Photovoltaic generating systems are to follow the guidelines set by UL 1741 standard (or latest version).

b. Suitable Equipment:
Inverter-based generating facilities which shall comply with UL 1741 standard (latest version) and IEEE 1547 (latest version). The Generating Facility shall be responsible for identifying the specific models of their protective devices. All protective devices shall be used in accordance with their intended application.

c. Review of Design Drawings:
The following engineering drawings and documents are required for review and approval by EDL prior to construction of the Generating Facility interconnection:

- A single-line diagram, relay list, trip scheme and settings of the Generating Facility, which identifies the Point of Interconnection, circuit breakers, relays, switches, synchronizing equipment, monitoring equipment, and control and protective devices and schemes.
- A three-line diagram which shows the Point of Interconnection, potential transformer (PT) and current transformer (CT) ratios, and details of the Generating Facility configuration, including relays, meters and test switches (not required for generating facilities < 30kW).

All drawings and documents shall be submitted to EDL for review.

Annex: Source Requirements Document

Part I – General

Electric service customers of Électricité du Laos ("EDL") seeking approval from EDL to interconnect and interoperate Distributed Energy Resources (DER) on EDL's grid must utilize inverter(s) that meet the certification testing requirements specified in this Source Requirements Document ("SRD"). The SRD shall be used in conjunction with IEEE 1547.1-2020 – *Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces*.

Normal and Abnormal Performance Category Requirement

For the application of this certification testing procedure, the following sets of performance categories are required:

1. Normal operating performance – Category B for voltage regulation performance and reactive power capability requirements (refer to IEEE 1547-2018, Clause 5); and
2. Abnormal operating performance – Category III for disturbance ride-through requirements (refer to IEEE 1547-2018, Clause 6).

Instructions for Certification Process

1. Use SRD to certify to IEEE 1547.1-2020 with UL 1741 Supplement SA or SB[1] as applicable with modifications to specific requirements listed in Part II – Non-Standardized Requirement below.
2. All other tests not listed in Part II – Non-Standardized Requirement certify to IEEE 1547- 2018 Category B of normal operating performance and Category III of abnormal operating performance requirements where applicable.
3. Electric service customers of EDL (working with their desired inverter manufacturer) must submit "Certificates of Compliance" and Results Reporting[2] spreadsheet from a nationally recognized testing laboratory ("NRTL") to EDL.
4. The Certificates of Compliance must indicate certification to EDL's SRD.

[1] UL 1741 Supplement name is not known at the time of the publication of this document. The supplement used should be aligned with IEEE 1547.1-2020.

[2] See also the 1547.1-2020 results reporting template form available at https://standards.ieee.org/downloads.html.

Part II - Non-Standardized Requirement

This section lists and describes the applicable requirements for capabilities or ranges of allowable settings that are different from IEEE 1547.1-2020 to help inverter manufacturers identify EDL changes. Tables along with their footnotes were copied from IEEE 1547-2018. Highlighted rows show the non-standard requirements. For normative reference purposes, the 1547-2018 values are shown.

A. Enter Service

For certification testing purposes, the performance during entering service (IEEE 1547-2018 subclause 4.10.3), randomized delay shall not be implemented or shall have the option to be disabled if implemented as an option alongside a soft start ramping function.

For test procedures in IEEE 1547.1-2020, refer to the following section:

- 5.6.2 Procedure (*Exception 1* shall not apply)

B. Frequency Ride-Through

For certification testing purposes, the use of SRD values is required.

IEEE 1547-2018 Table 19
Frequency Ride-Through Requirements for DER of Abnormal Operating Performance Category III
(see Figure H.10 from IEEE 1547-2018)

Frequency range (Hz)		Operating mode		Minimum time (s) (design criteria)	
1547-2018	SRD	1547-2018	SRD	1547-2018	SRD
f > 62.0	f >52.0	No ride-through requirements apply to this range			
61.2 < f ≤ 61.8	51.0 < f ≤ 52.0	Mandatory Operation[a]	Mandatory Operation[a]	299	299
58.8 ≤ f ≤ 61.2	49.0 ≤ f ≤ 51.0	Continuous Operation[a,b]	Continuous Operation[a,b]	Infinite[c]	Indefinite
57.0 ≤ f < 58.8	47.0 ≤ f < 49.0	Mandatory Operation[a]	Mandatory Operation[a]	299	299
f < 57.0	f < 47.0	No ride-through requirements apply to this range			

[a] Any DER shall provide the frequency-droop (frequency-power) operation for high-frequency conditions specified in 6.5.2.7.
[b] DER of Category I may provide the frequency-droop (frequency-power) operation for low-frequency conditions specified in 6.5.2.7. DER of Category III shall provide the frequency-droop (frequency-power) operation for low-frequency conditions specified in 6.5.2.7 of IEEE 1547-2018.
[c] For a per-unit ratio of Voltage/frequency limit of V/f ≤ 1.1.

For test procedures in IEEE 1547.1-2020 refer to the following sections:

- 5.5.3 Test for low-frequency ride-through
- 5.5.4 Test for high-frequency ride-through