Advanced Energy Partnership for Asia

KEY CONSIDERATIONS FOR ADOPTION OF TECHNICAL CODES AND STANDARDS FOR BATTERY ENERGY STORAGE SYSTEMS IN THAILAND

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List of Acronyms

BESS	battery energy storage system
NREL	National Renewable Energy Laboratory
OERC	Thailand Office of Energy Regulatory Commission
PV	photovoltaics
USAID	U.S. Agency for International Development

Executive Summary

The deployment of battery energy storage systems (BESS) is rapidly increasing throughout the world. This technology presents many opportunities for increasing contributions of variable renewable energy technologies, providing ancillary services, enabling energy access to remote areas, and increasing resilience during grid power outages. At the same time, BESS has not been widely deployed and operated in many contexts. The use of BESS requires codes and standards similar to those for other inverter-based technologies but may also necessitate special safety considerations in specific contexts.

As countries in Asia consider the inclusion of BESS in their power systems to meet policy objectives, renewable energy goals, increase resilience, and expand energy access, there is an opportunity to learn from the experiences of other regions and jurisdictions that have developed more advanced storage markets and practices. This report presents global best practices of codes, standards, and interconnection procedures developed to support the safe and reliable deployment of BESS. Several relevant case studies highlight current efforts to ensure safe operation of BESS and showcase potential pathways for adoption of relevant codes and standards. Specifically, this report is intended to support the Thailand Office of Energy Regulatory Commission (OERC) and other stakeholders in their efforts to develop technical codes and standards to govern the installation and operation of BESS; it may also be utilized as a guide for other countries as interest in the deployment of BESS technologies continues to grow.

Coupled with well-defined regulatory objectives, market incentives, permitting procedures, and technical review processes, the adoption of technical codes and standards that govern the design, construction, installation, and operation of BESS can help provide regulatory certainty, as well as reduce barriers to investment. Such codes and standards also ensure BESS deployment will meet national, regional, and local goals, while maintaining a reliable grid, and ensuring public safety. Finally, a robust BESS market can support the increased adoption of variable renewable energy generation technologies to meet Thailand's energy portfolio goals.

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1 Introduction and Background

Battery storage is "technology that enables power system operators and utilities to store energy for later use. A battery energy storage system (BESS) is an electrochemical device that charges (or collects energy) from the grid or a power plant and then discharges that energy at a later time to provide electricity or other grid services when needed" (Bowen, Chernyakhovskiy, and Denholm 2019). At the utility scale, BESS can help improve power system flexibility and support the integration of variable renewable energy into the power system by providing a range of services, including energy arbitrage, capacity (either firm or peaking), frequency regulation, resilience options such as black start capabilities, or even deferrals of transmission and distribution network expansion projects. Similarly, BESS connected directly to a retail customer can provide services including improved power quality and reliability, greater resilience, demand charge management, and time-variant energy charge management (Zinaman, Bowen, and Aznar 2020). Developing and prioritizing regulatory objectives and aligning these with larger policy goals is key to setting the market context for the deployment of BESS. Similarly, to understand how battery storage compares to other alternative technology options available that provide similar services, it is imperative for regulators and operators to consider how BESS resources are going to be utilized before designing specifications and requirements for the development of new BESS systems.

BESS is unique when compared to other electrical equipment in that it is generally always energized. This inherent characteristic necessitates the need to follow specific procedures and ensure safety measures are in place during the installation, commissioning, and operation of these systems (Akhil et al. 2013). There has been extensive research and testing into the safe operation of batteries, BESS modules, and BESS facilities.

This report provides an overview of international best practices on codes and standards developed to support the safe and reliable deployment of BESS. While multiple battery chemistries exist, each with unique safety and operational considerations, this report will focus on lithium-ion batteries. Specifically, this report is intended to support the Thailand Office of Energy Regulatory Commission (OERC) and other stakeholders in their efforts to develop technical codes and standards to govern the safe operations of BESS; it can also be used as a guide in other countries, as interest in the deployment of BESS technologies grows in a region. Additional work may be warranted to better understand how to design policy and incentive programs intended to encourage BESS adoption, address communication, control, and cybersecurity risks, as well as to address testing protocols and environmental concerns specific to a particular country, region, or grid system.

1.1 Current Thailand Context

Thailand currently has limited regulatory definitions of BESS or BESS components. BESS installation requests are approved on a case-by-case basis by the utility, which can complicate the interconnection process and introduce the potential for increased safety concerns. The development of BESS definitions would enable better understanding of the technology and technical requirements, thereby supporting proper design and a more rapid deployment of BESS in Thailand. This section is based on a series of interviews with key government stakeholders in Thailand, and provides a brief overview of the present regulatory context, government stakeholder needs, and ongoing efforts toward the development of BESS in Thailand.

The OERC has noted the need for guidelines for interconnection and development of BESS in Thailand. They noted that the cost of BESS is rapidly decreasing and the interest in the technology—both for grid-tied and remote applications—is increasing. The OERC has been tasked with developing the necessary codes, standards, and guidelines for the development of BESS in a variety of contexts in Thailand. Developing this regulatory framework will help ensure the safe and efficient interconnection of BESS in Thailand while also encouraging market adoption to help meet Thailand's energy goals.

BESS is often deployed alongside variable renewable energy technologies to reduce grid impacts and potential curtailment of the renewable generation. The OERC has noted that there is presently no provision in the Thai regulatory context that allows for BESS deployment with renewable energy generation to interact with the energy market for energy arbitrage. It should be noted that BESS is typically used with inverter-based technology as batteries are DC devices and BESS systems are generally being connected to the AC grid. As such, many of Thailand's existing codes and standards for interconnection of other inverter-based technologies—namely, solar photovoltaics (PV)—apply to the interconnection of BESS. But BESS can provide services in addition to generation. In these use cases, the governance of BESS differs from technologies that are solely generation-based.

For example, present interconnection standards for PV include provisions to prevent the unintentional islanding of local grid systems. It is important to prevent unintentional islanding of generation systems to ensure both electrical system protection (both customer and service equipment) and personnel safety; however, energy generation coupled with BESS, designed to act as stand-alone BESS installations when required, may provide additional benefits to the grid and to customers when intentionally islanded from the main grid using coordinated and sophisticated controls and operated as a microgrid to serve local load. The development of standards and codes could help support the deployment of stand-alone solar and BESS microgrids (also known as minigrids) for rural electrification in Thailand.

At the time of this writing, the Provincial Electricity Authority and the Electricity Generating Authority of Thailand were conducting a BESS pilot project in Mae Hong Son Province to support operations in the event of a power outage. The Provincial Electricity Authority is also in the early phase of implementing two additional microgrid projects in rural areas, in Yala Province and Ko Phaluai. Additionally, the Electricity Generating Authority of Thailand is conducting BESS pilot projects in Bamnet Narong District and Chai Badan District primarily for ancillary service support, while also exploring the use of BESS to provide other services, such as deferring network expansion, in other regions. The Metropolitan Electricity Authority has ongoing BESS pilot projects at low and medium voltage levels primarily for peak shaving and backup purposes. None of these projects are yet operational.

All government stakeholders noted the need for the development of technical standards and codes to help support streamlined, safe, and reliable deployment of BESS, and are intending to use lessons learned from ongoing pilots to inform this process. The Electricity Generating Authority of Thailand’s 2019 revision to grid codes includes considerations for BESS, but the Provincial Electricity Authority and the Metropolitan Electricity Authority have yet to make these updates; the Metropolitan Electricity Authority is considering a revision to their 2015 grid codes to specifically include BESS and inverter requirements. Developing guidelines, codes, and standards for BESS integration could streamline the process of deploying BESS for various applications as envisioned by policymakers and regulators in Thailand, as well as increase deployment of renewable energy to meet Thailand’s renewable energy goals.

Battery Safety Risks and Potential Mitigation: Arizona Case Study

In 2019, an explosion at a utility-scale lithium-ion battery station in Arizona, United States, sent four firefighters to the hospital with significant chemical inhalation burns. That event brought renewed attention to the need for safe design, operation, and maintenance of BESS facilities. While the vast majority of BESS facilities are interconnected and operated without incident, this case study provides valuable lessons in the safe operation of BESS.

The fire occurred on a single rack that contained 14 battery modules. The monitoring systems detected a voltage drop across the impacted modules, followed by a rapid increase in temperature. Notably, the design of the system kept the fire from spreading to the additional 1.5 MWh of battery storage in the system. The unique characteristics of BESS require appropriate, manufacturer specified discharge procedures for disassembly and it took 9 weeks and the removal of 364 additional batteries before investigators could get to the damaged rack (Spector 2019).

Initial findings concluded that an internal cell failure in a single battery started a cascading thermal runaway event—a situation where energy in the battery was suddenly released, causing a rapid rise in temperature (DNV GL 2020) (Spector 2019). At the time of this writing, the battery maker, LG Chem, was disputing the cause of the fire before the Arizona Corporation Commission (the Arizona regulatory agency). An analysis commissioned by LG concluded that an external heat source—such as electrical arcing—was the likely cause of the thermal runaway (Exponent, Inc. 2020). In either case, the resulting rapid rise in temperature evaporated the electrolyte mixture into a gas-air mixture, which eventually ignited. The explosion then happened due to a buildup of these gases and the opening of the containment door. Additional factors included a lack of thermal barriers between cells, a fire suppression system incapable of stopping thermal runway, and a lack of procedures related to extinguishing, ventilation, and entry in the emergency response plan (DNV GL 2020) (Arizona Public Service 2019).

The release of gases has become a major safety consideration for operators of BESS facilities. States like New York have passed legislation requiring ventilation on BESS facilities to prevent the buildup of gases, the U.S. Department of Energy has designed programs to train emergency personnel how to respond to BESS fires, and a new emphasis on safety was included in many BESS procurement processes.

The explosion and injuries in Arizona represent a worst-case-scenario for BESS safety. In reality, the vast majority of BESS systems have been operating safely for months or years. However, it also gives researchers, decision makers, and developers the opportunity to understand the hazards that may be associated with BESS systems. In the Arizona case, the development company had safely designed and built BESS facilities for over a decade before this event, and the utility had operated the facility for over 2 years with no issues. This shows that in this fledgling industry, standards and codes need to be constantly updated to improve system design and address other technological issues that can cause failure. Subsequent sections of this report will discuss these hazards and the technical and process solutions to minimize the associated risks.

2 Global Best Practices on BESS Safety and Technical Standards

BESS is a rapidly evolving technology. Battery chemistries are constantly evolving, and costs are declining for systems and many battery technologies. As such, it is important to review and update codes, standards, and guidelines for the deployment of BESS. The case studies presented in this section represent jurisdictions that have sought to develop robust BESS practices that ensure grid reliability and personnel safety while also encouraging the deployment of BESS. The Australian case emphasizes the use of existing codes and standards mixed with local codes to govern safety issues. The New York case specifically explores the design of the facilities that contain BESS with the goal of ensuring public safety. Driven by policy, California still has the largest storage market in the United States and has seen residential (backup system) storage grow rapidly following recent wildfires and subsequent utility blackouts (Wood Mackenzie and Energy Storage Association 2020).

As Thailand considers BESS technologies to support renewable energy goals, improve power system flexibility, energy access, and resilience, and address other needs, these relevant case studies provide insight on how other countries and jurisdictions have navigated this rapidly evolving landscape. Several model codes, equipment and interconnection standards (e.g., IEEE 1547-2018) already exist, and the OERC may consider adopting these existing resources and adapting them to suit local conditions and grid requirements as a starting point.[1] In particular, the updated IEEE 1547-2018 is a key industry standard for the interconnection of distributed energy resources to the grid.[2] UL 9450, the Standard for Energy Storage Systems and Equipment, governs the safety aspect of BESS systems such as the separation of cells, size requirements, and testing procedures for thermal runaway fire propagation. Similarly, UL 1741 is a certification standard for equipment testing, and covers inverters and other interconnection system equipment intended for both off-grid and grid-connected systems. Along with other standards and codes, both IEEE 1547-2018 and UL 1741 have been adopted in some way by most U.S. states as binding interconnection and equipment requirements, and could also provide a good foundation for Thailand (Zinaman, Bowen, and Aznar 2020). Currently under development, IEEE P2800, Standard for Interconnection and Interoperability of Inverter-Based Resources Interconnecting with Associated Transmission Power Systems will provide guidance and key recommendations for safe integration of inverter-based technologies to the bulk power system.

There are several potential pathways for the adoption of codes, standards, and regulations, which involves an official decision to implement, requirements for compliance, and enforcement mechanisms (Rosewater and Conover 2018). As model codes and standards are updated from time to time, newer editions must be specifically adopted soon after publication of revisions. These can be adopted by a government entity, through utility requirements, or via other mechanisms like insurance policies or incentive programs, as can be seen in the following call-out box.

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[1] IEEE 1547 was developed as a 60-Hz standard; however, it has been successfully adapted to 50-Hz grid systems in different parts of the world. For example, IEC 61727 is a frequently used standard for PV systems in Europe, which works in conjunction with IEEE 1547 (A. K. Jain et al. 2019). The final development of codes and standards for Thailand should include these considerations.

[2] For a more thorough clause-by-clause summary of IEEE 1547-2018, refer to the 2020 NREL technical report, *Clause-by-Clause Summary of Requirements in IEEE Standard 1547- 2018*, available at https://www.nrel.gov/docs/fy20osti/75184.pdf.

Pathways for Adoption of Codes and Standards
(Rosewater and Conover 2018)

- **Government**: A mandatory requirement through legislative or regulatory action or as a condition for program participation or funding.
- **Utility**: As managed by a regulatory commission and acting as the authority having jurisdiction for their systems on both behind the meter and on the grid side of the meter.
- **Insurance provider**: A requirement as a condition of insurance coverage.
- **Licensing**: Requirement of compliance with certain technical requirements by a licensing board as a condition for licensure.
- **Building developer or financial institution**: Building specifications issued while developing/underwriting a project.
- **Stakeholders considering BESS deployment**: Voluntary application of model codes or standards for self-adoption in the absence of other mandatory requirements.

2.1 Australia

Australia has faced numerous wildfires and heatwaves over the past decade. These events have led to recognition of the importance of understanding the thermoregulation of BESS facilities. Australia primarily uses BESS at the bulk power level but also has a robust market for distributed storage that is most often associated with on-site solar PV (AI Group et al. 2018). To address safety concerns of BESS facilities, as well as set consistent and transparent standards, Standards Australia jointly with Standards New Zealand, developed *AS/NZS 5139:2019, Electrical installations — Safety of battery systems for use with power conversion equipment* in October 2019. The authors specifically noted that existing battery installation standards were developed for traditional lead-acid chemistries that do not reflect the current battery storage market (Standards Australia 2019). The authors additionally noted that advances in interconnection equipment and standards necessitated the updating of existing requirements. The joint Australia/New Zealand standard is considered a best practice guide for a variety of storage technologies and scenarios. It should be noted that AS/NZS 5139 is intended to be used in coordination with over 30 existing codes and standards, such as *AS 3731, Stationary batteries* and multiple sections of the International Electric Code (Standards Australia 2019). The authors of the document also acknowledge the changing nature of the BESS market and note that the standards will require periodic updates to stay relevant to changing conditions. Finally, the authors state that the standard "contains a substantial number of informative components so that the level of knowledge and understanding in this new field of technology and its application is increased and so that this information can act as a guide for interested parties." They provide this information using two categories: normative and informative. Normative information applies directly to part of a relevant standard; the informative category provides general background and/or guidance.

AS/NZS 5139 applies to battery modules, pre-assembled battery systems, and pre-assembled integrated battery energy systems. The standard also applies to auxiliary equipment and battery management systems (AI Group et al. 2018). All of these technologies are specifically defined by Standards Australia, as will be discussed later.

In addition to AS/NZS 5139, the Australian Industry Group (AI Group), working with other stakeholder groups in Australia, has produced the *Best Practice Guide: Battery Storage Equipment Electrical Safety Requirements* (hereafter "Safety Guide") (AI Group et al. 2018). This guide gives main standards, secondary standards, and additional requirements for BESS installation in Australia to aid developers in understanding codes, standards, and other requirements. The guide denotes primary and secondary standards as preexisting regulations (such as international electric code), and points users to the existing standard. *Additional Requirements* are then requirements placed on BESS facilities in Australia that meet certain pre-specified conditions. This document leads decision makers through a guide to determine which of the standards and requirements apply to each system.

Requirements for BESS

Australia has developed clear definitions and requirements for BESS and associated components. The guide contains 79 specific definitions ranging from what constitutes a "toxic fume" to more ambiguous terms such as "reasonably practical" (AI Group et al. 2018). The entire list of definitions can be found in Section 1.3 of the standard. These definitions are key to enforcement of BESS codes and standards. Such definitions aid in the efficient development of BESS by removing ambiguity from terms used by developers, customers, and utilities. Similar definitions could be adopted in Thailand to aid in efficient deployment of BESS.

Additional Requirements

Australia has significant geography, topography, and climate variation. As such, the Australian government has noted that additional requirements may be warranted, depending upon the location and type of installation. The following considerations are some site-specific constraints placed on BESS installations in hazard prone areas that may also be relevant for specific locations within Thailand. The use of GIS platforms or mapping may indicate the locations where these additional requirements apply.

External fire protection: Parts of Australia have regular wildland fires. BESS located in these areas are required to comply with UL 1973. Given recent fire events, this requirement is being considered for application to all BESS facilities.

Salt mist and fog: BESS facilities impacted by salt mist and fog must comply with IEC 60068-2-52 Ed3 2017.

Wind loading: In areas of high wind loading, BESS facilities must comply with local wind hazard building requirements, as noted in AS1170:2:2011.

Risk Matrix

The Safety Guide notes specific hazards of concern and seeks to minimize those hazards (AI Group et al. 2018). The listed hazards include:

- Arc flash
- Chemical hazards
- Storage and transportation accidents prior to installation
- Vibration from transport or seismic activity
- UV protection
- Cybersecurity.

To facilitate understanding of these risks, AI Group has released the Battery Storage Risk Assessment Matrix (a free Microsoft Excel tool[3]) with the Safety Guide. This tool was released to aid decision makers in understanding and reducing risks associated with their battery storage projects. The Excel tool also aids in determining if the risks to any specific system warrant application of the additional requirements listed above.

2.2 New York

The U.S. state of New York seeks to reduce risks associated with BESS facilities by utilizing codes, standards, and training (NYSERDA 2019). The density of population in the New York City metro area has led to BESS installations near or even inside of occupied spaces. New York divides their building-related requirements into categories of "occupied" and "nonoccupied" spaces, where the latter (for example, outdoor energy storage containerized systems) may have less restrictive codes (NYSERDA 2019). The aim of these categories is to minimize fire and chemical hazards to building occupants.

[3] https://batterysafetyguide.com.au/

New York also seeks to minimize conditions under which fires occur in BESS applications. Most reported and studied fires in BESS installations to date occurred under one or more of the following abuse conditions (DNV GL 2017):

1. Low ambient pressure
2. Overheating
3. Vibration
4. Shock
5. External short circuit
6. Impact
7. Overcharge
8. Forced discharge.

Codes in New York seek to minimize the occurrence of these conditions. As also noted in the Arizona case study, the gas and air buildup around modules and batteries are generally the ignition points for fires (DNV GL 2017). New York code requires ventilation of all enclosed BESS systems to prevent this buildup (NYSERDA 2019). However, it is also noted that off-gassed "concentrations of HCl reach a threatening level much faster than the concentrations of flammable gases" so ventilation sized to adequately vent HCl (hydrogen chloride) will automatically fulfill requirements for removal of flammable gases (NYSERDA 2019). It is also noted that outdoor systems will have to design for heat and plume considerations near inhabited buildings. This is to minimize the local impacts of potentially hazardous plumes on the population (NYSERDA 2019).

Similar to Australia, New York utilizes a mix of existing international and national codes coupled with state-specific battery codes to create a framework for BESS installation. The primary codes for safety standards related to BESS in New York include the International Building Code, the International Fire Code 608, National Fire Protection Association Chapter 52 *Energy Storage Systems,* and the Fire Department of New York Certificate of Fitness B-29 *Supervision of Battery Systems and Other Related Equipment* (DNV GL 2017). These codes are primarily considerations for minimizing fire-related risks. Additional environmental hazards and risks are not considered in these codes.

Also similar to Australia, New York has codified the definitions of BESS and related systems. Some of the key definitions include:[4]

Battery: A single cell or a group of cells connected electrically in series, in parallel, or a combination of both, which can charge, discharge, and store energy electrochemically. For the purposes of this law, batteries utilized in consumer products are excluded from these requirements.

Battery Energy Storage Management System: An electronic system that protects energy storage systems from operating outside their safe operating parameters and disconnects electrical power to the energy storage system or places it in a safe condition if potentially hazardous temperatures or other conditions are detected.

Battery Energy Storage System: One or more devices, assembled together, capable of storing energy in order to supply electrical energy at a future time, not to include a stand-alone 12-volt car battery or an electric motor vehicle. A battery energy storage system is classified as a Tier 1 or Tier 2 Battery Energy Storage System as follows: A. Tier 1 Battery Energy Storage Systems have an aggregate energy capacity less than or equal to 600kWh and, if in a room or enclosed area, consist of only a single energy storage system technology. B. Tier 2 Battery Energy Storage Systems have an aggregate energy capacity greater than 600kWh or are comprised of more than one storage battery technology in a room or enclosed area.

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[4] The full list of definitions can be found in the NYSERDA BESS storage guidebook: https://www.nyserda.ny.gov/All%20Programs/Programs/Clean%20Energy%20Siting/Battery%20Energy%20Storage%20Guidebook

Cell: The basic electrochemical unit, characterized by an anode and a cathode, used to receive, store, and deliver electrical energy.

New York also requires that BESS developers provide a decommissioning plan at the time of installation. This plan must include a description of decommissioning activities and responsible parties, a disposal plan for all hazardous waste, the anticipated life of the BESS, estimated decommissioning costs, assurance that funds will be held for decommissioning, the method for restoring the site, and contingencies for removal of operational BESS from service.

Finally, New York requires that all BESS equipment comply with technology standards. Key standards are listed below. Refer to Table 1 for a brief description.

- UL 9540, Safety of Energy Storage Systems and Equipment
- UL 1973, Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications
- UL 1642, Lithium Batteries
- UL 1741 or UL 62109, Inverters, Converters, Controllers, and Interconnection System Equipment for Use with Distributed Energy Resources or Safety of Power Converters for Use in Photovoltaic Power Systems.

2.3 California

In 2013, the California Public Utilities Commission adopted a 1,325-MW energy storage procurement mandate for the state's three investor-owned utilities by 2020, with specific targets for transmission-connected, distribution-connected, and customer-side energy storage systems (CPUC 2013). These targets were further expanded to include an additional 500 MW of behind-the-meter storage in 2017 (CPUC 2017a). California's utilities are making steady progress toward these ambitious goals as the state responds to the challenge of developing and updating codes, standards, and guidelines to keep up with the pace of regulatory requirements.

The Public Utilities Code defines an energy storage system as:

> "…commercially available technology that is capable of absorbing energy, storing it for a specified period, and then dispatching the energy. An energy storage system may be centralized or distributed and will accomplish one or more of the following:
>
> Reduce emissions of greenhouse gases.
>
> Reduce demand for peak electrical generation.
>
> Defer or substitute for an investment in generation, transmission, or distribution assets.
>
> Improve the reliable operation of the electrical transmission or distribution grid."

Like Australia and New York, California relies on a combination of international and national codes to provide safety best practices and standards for the installation of energy storage. These broadly cover installation, certification, fire protection, and more. While BESS technology standards are evolving as the technology develops, key standards identified by the California Public Utilities Commission are listed below (CPUC 2020). A list of some of the key standards and codes can be found in Table 1.

- UL 1973, Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications
- UL 9540, Safety of Energy Storage Systems and Equipment
- California Building Standards Code
- NFPA 1, Fire Code
- NFPA 70, NEC:
  - NEC 480, electrical requirements for stationary installations of electrical battery storage
  - NEC 705, interconnected electric power production sources.

The California Public Utilities Commission also directed its Safety and Enforcement Division to develop guidelines for its inspectors to use in reviewing energy storage devices at utility-owned sites. The Safety and Enforcement Division worked with utility, industry representatives, and code and technical standards experts to develop a set of guidelines for documentation and safe practices at energy storage systems installations.[5]

Further, the California Generator Interconnection Rule 21 "describes the interconnection, operating and metering requirements for generation facilities to be connected to a utility's distribution system." [6] Each of the state's three investor owned utilities has its own tailored version of the rule, which governs various parts of the interconnection process, including technical requirements for interconnecting equipment, procedures for application review, system evaluation and dispute resolution. Rule 21 has been revised and improved since its initial adoption in 1982, and is currently under development to consider the use of power flow analysis to inform siting decisions and streamline the approval process for qualifying projects (CPUC 2017b).

For connection to the bulk power system, projects are considered on a case-by-case basis, and depending on the location, must follow either the California Independent System Operator interconnection process and requirements or follow requirements for an interconnection with the specific utility that serves the territory (CAISO 2020).

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[5] The Safety and Enforcement Division Safety Inspection Checklist can be found here: https://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/Safety/Risk_Assessment/SED%20Safety%20Inspection%20Checklist%20Final%20042717.pdf.

[6] Addition information about Rule 21 can be found here: https://www.cpuc.ca.gov/Rule21/.

Table 1. Selection of Key Standards and Model Codes Addressing Energy Storage Technology Safety

Adapted from Cole and Conover 2016; Rosewater and Conover 2018; ESA 2019; Searles and Paiss 2020

BESS Components	**IEEE P1679.1** Guide for the Characterization and Evaluation of Lithium-Based Batteries in Stationary Applications **IEEE P1679.2** Guide for the Characterization and Evaluation of Sodium-Beta Batteries in Stationary Applications **IEEE P1679.3** Draft Guide for the Characterization and Evaluation of Flow Batteries in Stationary Applications **UL 1973** Stationary, Vehicle Auxiliary Power and Light Electric Rail Applications **UL 1974** Evaluation for Repurposing Batteries **UL 810A** Electrochemical Capacitors
Complete BESS	**IEEE 1679** Recommended Practice for the Characterization and Evaluation of Emerging Energy Storage Technologies in Stationary Applications **UL 1642** Lithium Batteries **UL 1741 and UL 1741SA** Inverters, Converters, Controllers, and Interconnection System Equipment for Use with Distributed Energy Resources **UL 9540** Safety of Energy Storage Systems and Equipment **UL 9540A** Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Installation of BESS	**NFPA 111** Standard on Stored Electrical Energy Emergency and Standby Power Systems **NFPA 855** Standard for the Installation of Stationary Energy Storage Systems **NECA 416** Recommended Practice for Installing Energy Storage Systems **FM Global Property Loss Prevention Data Sheet # 5-33** Electrical Energy Storage Systems **DNVGL-RP-0043** Safety, Operation, and Performance of Grid-Connected Energy Storage Systems (GRIDSTOR)
Safety of the Built Environment	**NFPA 1** Fire Code **NFPA 70** National Electrical Code [NEC] **NFPA 110** Standard for Emergency and Standby Power Systems **NFPA 5000** Building Construction and Safety Code **IBC** International Building Code **IFC** International Fire Code **IEEE C2** National Electric Safety Code [NESC] **Local zoning codes** **Local building standards and codes**
Interconnection Process and Standards	**IEEE 1547-2018** Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

	IEEE P1547.9 Guide to Using IEEE Standard 1547 for Interconnection of Energy Storage Distributed Energy Resources with Electric Power Systems **Rule 14H** Hawaii Interconnection of Distributed Generating Facilities with the Company's Distribution System **Rule 21** California Generator Interconnection **TIIR** State of Minnesota Technical Interconnection and Interoperability Requirements **IEEE P2800** Standard for Interconnection and Interoperability of Inverter-Based Resources Interconnecting with Associated Transmission Electric Power Systems (under development)

3 Key Considerations for Thailand

Many national, regional, and local jurisdictions are developing codes, standards, and guidelines for BESS. As such, lessons can be applied to the development of the BESS regulatory framework for Thailand. As codes, standards, and guidelines are adopted, it is key to consider the local context. For example, Thailand has both dense cities (reflective of New York) and rural areas. The safety standards related to these contexts are likely to differ based on the proximity of populations to battery installations. Additionally, Thailand's hot, humid climate—more similar to that of Australia's coastal region—may warrant additional environmental considerations to ensure the safe operation of BESS. It is also important to note that the BESS market, as well as the associated technology, changes quickly. It is therefore important to revisit and update codes, standards, and guides on a periodic basis to reflect these changes.

3.1 Energy Storage System Components

As shown in the case studies above, it can be useful to define terms for BESS and related components. New York's BESS guidebook and Australia's risk matrix both provide language on definitions and descriptions of BESS that could be adapted to the context of Thailand. Additionally, the case studies show a need to include provisions to use standardized or tested equipment. For ease of system permitting, the OERC may consider issuing or adopting a list of approved equipment for BESS installers to reference.[7] These lists are updated regularly to reflect the changing nature of technology and equipment standards.

3.2 Safety

Fire hazards associated with BESS facilities are primarily a function of flammable gas buildup. As such, ventilation of facilities is key to reducing this risk. It should be noted that in densely populated areas, consideration should be given to the local population when designing the ventilation and the air transport of hazardous gases. Ventilation is ideally designed to remove toxins away from populations or critical environments.

Abuse conditions, such as the eight noted in New York, are most often the cause of released flammable gases. Those conditions should be minimized to reduce fire risk. These conditions are minimized during the installation of BESS as well as in the transportation and storage of the components. It is important to ensure safe conditions of the equipment for the entire life cycle (production to disposal) of the BESS components.

BESS is susceptible to overheating. Given the annual weather conditions in Thailand—particularly days over 30 degrees Celsius—cooling provisions may be required to ensure that overheating of BESS installations does not occur. This type of requirement may be site-specific. Additional site-specific requirements may also be considered for coastal areas where sea fog and sea spray could come in contact with BESS installations. As noted in the Australia case study, one method of reducing risks at these sites is to require additional weather sealing that is rated for sea spray environments. Note that the weather sealing should be included in initial system design so as not to interfere with ventilation.

3.3 Procurement

As noted in the case studies, many jurisdictions require that all equipment comply with testing requirements and UL standards. While some jurisdictions develop their own equipment standards, it is often easier for regulatory bodies to adopt existing equipment standards and lists to avoid the need for constant updates to keep up with changing technologies.

3.4 Interconnection

Interconnection of BESS is primarily governed by IEEE 1547-2018 and IEEE P2800 (under development). These standards govern the interconnection of inverter-based technology to the electrical grid. It may be most expedient for OERC to adopt IEEE 1547-2018 and IEEE P2800 for BESS interconnection rather than developing new

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[7] For example, the California Energy Commission Solar Equipment Lists include equipment that meets established safety and performance standards. They include information about PV modules, inverters, meters, BESS, and other related information, and are updated three times a month: https://www.energy.ca.gov/programs-and-topics/topics/renewable-energy/solar-equipment-lists.

standards. It should be noted that IEEE updates their codes and standards on a periodic basis to reflect the rapid changes in inverter-based technologies. As such, the OERC may adopt updated codes as they become available.

BESS interconnection processes may vary based on how the BESS is used. BESS can be both a storage load to provide grid services and/or a generation resource (i.e., four-quadrant operation). The process for developing and interconnecting BESS must therefore enable the end goal of each system.

3.5 Ancillary Services

BESS can function on different timescales than traditional resources and are often capable of discharging in a fraction of a second (Gevorgian, Baggu, and Ton 2019). This makes BESS ideal for providing ancillary services needing rapid response such as Primary Frequency Response, voltage support, or black start capabilities. In 2019, the primary utilization of BESS in the United States was for operating reserves and ancillary services (Bowen, Chernyakhovskiy, and Denholm 2019). While not directly related to the development of technical codes and standards, the OERC may consider designing BESS programs that incentivize or encourage ancillary services most needed in Thailand, as utilities look to utilize BESS to provide these services.

3.6 Relevant Interconnection Standards and Codes

As shown in the case studies, most BESS codes point to existing codes and standards related to the electric grid, chemical safety, and the design and installation of stand-alone energy systems. The primary codes to consider for adoption related to BESS installation include[8]:

- IEEE 1547-2018, Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces
- IEEE P2800 (under development), Interconnection and Interoperability of Inverter-Based Resources Interconnecting with Associated Transmission Electric Power Systems
- UL 9540, Safety of Energy Storage Systems and Equipment
- UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
- UL 1741, Inverters, Converters, Controllers, and Interconnection System Equipment for Use with Distributed Energy Resources.

[8] Many of these standards were developed for 60-Hz systems; however, they have been successfully adapted to 50-Hz grid systems throughout the world. The final development of codes and standards should include these considerations.

4 Next Steps

The first step in developing codes, standards, and processes for BESS is to identify objectives for BESS in Thailand. These objectives will likely vary by location and local grid needs and might also change as the contribution of variable renewable energy increases in Thailand and additional fast frequency response capabilities become necessary.

As of this writing, the OERC has identified four use cases for BESS, and, with support from USAID Clean Asia, is reviewing existing gaps in codes and standards. Building on this effort and the BESS technical standards roadmap provided by USAID Clean Power Asia, the most expedient path to addressing potential gaps could be to adopt existing international model codes and standards related to BESS (e.g., IEEE 1547-2018, UL 1741, and UL 9450). Adoption language that includes provisions for compliance with the latest updates to standards also could reduce the need for multiple OERC revisions as technologies and standards change. Formal adoption of standards through regulatory or legislative processes could provide increased certainty to private sector stakeholders with interest in the Thai BESS market. Implementation of a transparent process for updating codes and standards could further reduce barriers to private sector engagement in Thai BESS deployment.

As shown in the case study examples in Section 2, some requirements or standards for BESS may be location-dependent. Developing a publicly available mapping system to show hazards specific to BESS safety, including sea salt spray, earthquake risks, flood zones, and population density, may clarify locations where enhanced BESS standards may be required.

Training may also be needed for the successful development of a BESS market in Thailand. Initial training on new codes and standards for BESS interconnection and procurement could reduce confusion and streamline process and interconnection timelines for BESS owners and installers. Additionally, the New York BESS standards note the need for additional training for emergency personnel who respond to fires in or near BESS facilities. Thai emergency responders may equally benefit from such training.

Finally, as Thailand is looking to use BESS to provide a variety of services to support power system needs, putting in place enabling policy framework and market incentives could help further develop a BESS market.

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