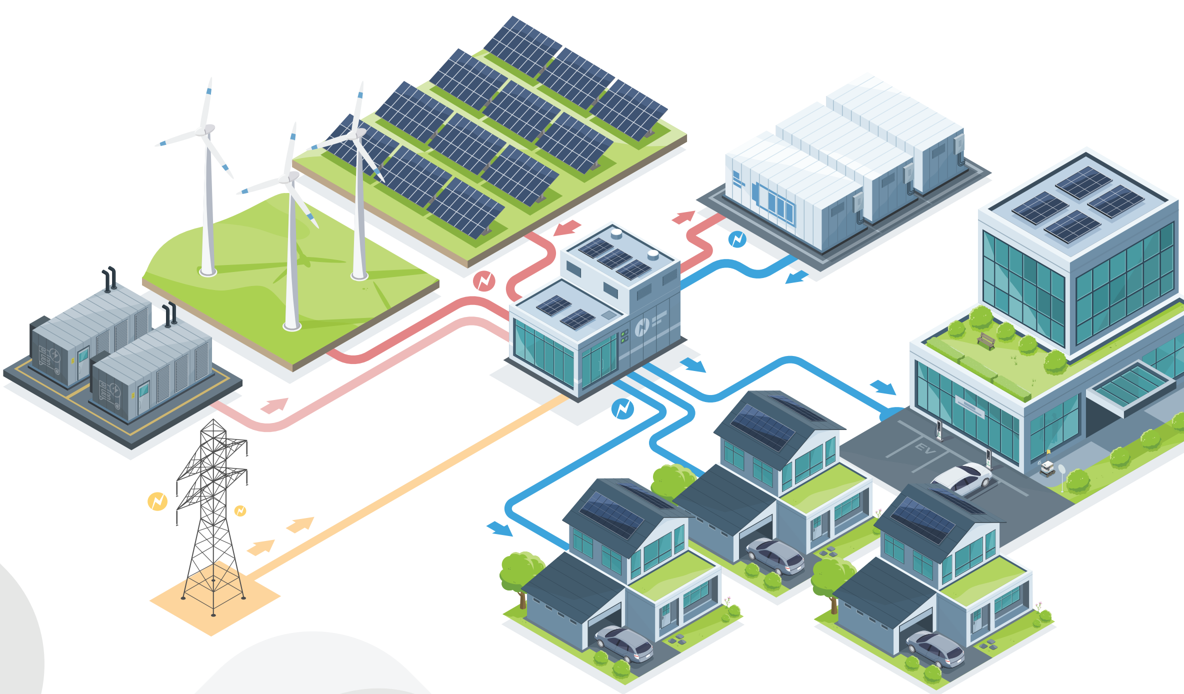
On behalf of:
Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany
IKI INTERNATIONAL CLIMATE INITIATIVE
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
teri The Energy and Resources Institute
Creating Innovative Solutions for a Sustainable Future

Battery Assembly and Container Testing

Safety, Global Best Practices and Way Forward



As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

The Energy and Resources Institute (TERI)

Registered offices

Bonn and Eschborn

New Delhi

Energy Storage for Renewable Energy Integration in India (StoREin)
B-5/5, Safdarjung Enclave, New Delhi 110 029 India
T: +91 11 4949 5353
F: + 91 11 4949 5391
I: www.giz.de/india

Responsible

Mr. Bernhard Max Voelcker, Project Manager
Energy Storage for Renewable Energy Integration in India (StoREin)
E: bernhard.voelcker@giz.de

Authors

Ms Prachi Saini, Associate Fellow, TERI
Mr Kapil Muddineni, Fellow, TERI
Mr Mukesh Kumar, Associate Fellow, TERI

Reviewers

Mr Richie Stephen, UL Standards and Engagement
Mr Debmalya Sen, IESA
Prof. Zakir Rather, IIT Bombay
Mr Alekhya Datta, TERI
Ms. Bhagyasree, GIZ
Ms. Nupur Sharma, GIZ

Design and Layout
TERI

On behalf of the

Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN) under the umbrella of the International Climate Initiative (IKI)

Acknowledgements

This work has been prepared by The Energy and Resources Institute (TERI) as part of the Indo-German technical cooperation project *Energy Storage for Renewable Energy Integration in India (StoREin*)*. Commissioned by the Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN) under the umbrella of the International Climate Initiative (IKI), the StoREin project is led by the Ministry of New and Renewable Energy (MNRE), Government of India, and jointly implemented with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. The StoREin project has played a significant role in strengthening technical cooperation on energy storage in India by fostering policy dialogue, promoting knowledge exchange, supporting capacity development, and facilitating collaboration among government, industry, academia, and research institutions.

We express our sincere gratitude to Shri Sunil Sharma, Director, Ministry of Power, Government of India, for providing the opportunity and strategic direction to undertake this work, and for his continuous engagement in advancing national energy storage priorities.

We also acknowledge the continued leadership, guidance, and support of the Energy Storage Division of Ministry of New and Renewable Energy (MNRE), Government of India, which has been instrumental in advancing the project's objectives and facilitating this work.

The project gratefully acknowledges the guidance and support provided by stakeholders from research organizations, testing laboratories, industry partners, and knowledge institutions, including UL Standards & Engagement, India Energy Storage Alliance (IESA), Customized Energy Solutions (CES), and Grid Integration Lab IIT Bombay, who contributed valuable insights and evidence that informed the development of this study. Their inputs, ranging from national standards and international best practices to incident analyses and operational learnings, have been invaluable in shaping a comprehensive and forward-looking assessment of Battery Energy Storage Systems (BESS) safety requirements in India.

* Details available at <https://www.international-climate-initiative.com/en/project/energy-storage-for-renewable-energy-integration-in-india-storein-22-i-489-ind-g-storage-for-re-integration-storein/>

Table of Contents

List of Figures

List of Tables

Executive Summary

India's energy transition is at a pivotal juncture, with national planning frameworks signalling a steep and time-bound increase in energy storage deployment. According to the Central Electricity Authority's National Electricity Plan (NEP 2023), storage requirements are projected to grow from 82.37 Gigawatt-hours (GWh) by 2026–27 to 411.4 GWh by 2031–32, including 236.22 GWh of Battery Energy Storage Systems (BESS) placing India firmly on a trajectory to exceed 80 GWh of installed battery storage capacity by 2030.[1] This rapid scale-up underscores the critical role of storage in enabling renewable integration, grid stability, and energy security.

However, this expansion is accompanied by heightened safety concerns, particularly as deployments transition from pilot-scale to utility-scale, megawatt-hour (MWh) and gigawatt-hour (GWh)-level systems. While government initiatives such as Viability Gap Funding (VGF) and policy incentives have catalysed early adoption, safety frameworks have not kept pace with the scale and complexity of deployment. Recent global and domestic incidents have demonstrated that BESS, if not adequately designed, tested, and regulated, can pose risks including thermal runaway, fire propagation, toxic gas release, and cascading system failures.

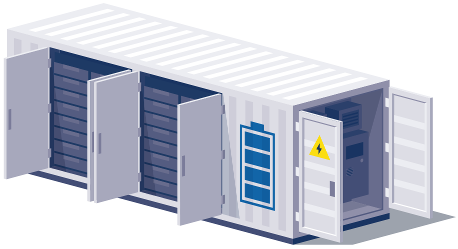
India's current regulatory ecosystem reflects strong progress at the cell and module level, with established standards for component safety and performance. However, a critical gap persists at the system level, particularly for containerized, grid-scale BESS installations. The country currently lacks dedicated national infrastructure for large-scale fire testing, thermal runaway propagation assessment, and full-system validation under real-world operating conditions. This gap limits the ability to evaluate how failures propagate across modules, racks, and containers an essential requirement for ensuring safe deployment at scale.

In contrast, global frameworks adopt a more comprehensive, system-oriented approach. Standards such as UL 9540, IEC 62933, and NFPA 855 define protocols for risk assessment, system design, fire safety, and emergency response, emphasizing end-to-end validation of fully integrated systems.

Against this backdrop, India faces a strategic imperative to bridge the gap between deployment ambition and safety assurance. Without robust system-level standards, testing infrastructure, and regulatory alignment, the rapid scale-up of BESS could expose stakeholders such as utilities, developers, financiers, and communities to operational, financial, and reputational risks.

This paper therefore undertakes a comprehensive review of global best practices, assesses India's current capabilities across standards, testing, and certification frameworks, and identifies key technical, institutional, and regulatory gaps. It further proposes a structured road map for establishing a safe, resilient, and future-ready BESS ecosystem in India.

1 Details available at <https://mnre.gov.in/en/energy-storage-systemsess-overview/>



1. Introduction and Scope

The rapid expansion of Megawatt (MW) scale grid connected Battery Energy Storage Systems (BESS) is reshaping modern power systems, enabling large scale renewable energy (RE) integration, peak load management, and enhanced grid stability. Battery storage is now among the fastest growing energy technologies globally; recent analysis from the Ember Global Electricity Review (2026) shows that global battery deployment increased by around 46% in 2025, reaching an estimated 250 GWh of new battery storage capacity additions, as falling costs accelerated adoption and supported the integration of solar power,[2] reflecting the rapid scaleup of storage to support RE integration and grid flexibility, driven largely by utility-scale deployments that improve system flexibility and reduce curtailment.

Markets in China and the United States continue to dominate deployments, while emerging regions such as Saudi Arabia, Australia, and Chile are increasingly contributing to global build out momentum.[2] This rapid scale up highlights the critical role of BESS in supporting RE integration and grid resilience worldwide.

As deployment size increases from Kilowatt (kW) to Megawatt (MW), so do the associated safety challenges particularly for high-energy density lithium–ion technologies. Although reported numbers of incidents/accidents are limited, the consequences can be severe. The primary hazard is thermal runaway, an exothermic reaction triggered by internal short circuits, mechanical damage, manufacturing defects, or overcharging. A compact containerized BESS, a single-cell failure can propagate from cell → module → rack→ container, producing intense heat, pressure rise, and flammable gas accumulation as shown in Figure 1. Documented field incidents reveal patterns such as cascading thermal runaway, accumulation of unburned gases, and delayed ignition or explosion during emergency access.[3]

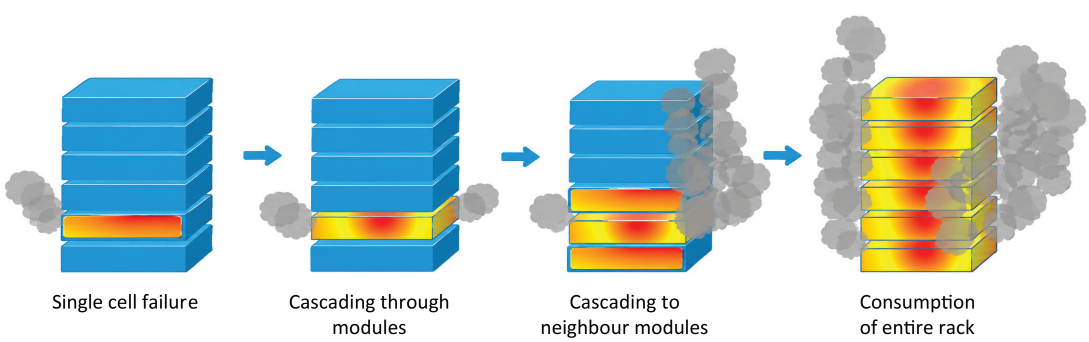


Figure 1 A single-cell failure propagated through one module

Scientific studies further show that Li–ion battery fires differ significantly from conventional hydrocarbon fires. Full scale testing has quantified hazardous releases of Hydrogen Fluoride (HF) and Phosphoryl Fluoride

[2] Details available at <https://ember-energy.org/app/uploads/2026/04/Global-Electricity-Review-2026.pdf>

[3] Details available at <https://www.nerc.com/globalassets/programs/event-analysis/lessons-learned/ll20210301_battery_storage_cascading_thermal_runaway.pdf

(POF_3) often in the range of 20–200 mg/Wh[4] creating acute toxicity risks in enclosed BESS environments and reinforcing the need for engineered ventilation and gas management systems.

Global experience clearly states that component-level compliance is insufficient for ensuring safe system operation. Many earlier BESS incidents involved pre-standardization installations lacking robust testing, container-level safeguards, and integrated detection/suppression strategies.[5] Table 1 summarizes key incidents discussed in this paper, highlighting their causes, consequences, and critical lessons learned.

Table 1 Global BESS incidents highlighting causes and observed impacts

Incident / location	Year	Primary cause	Consequences	Key lessons learned
Surprise (McMicken) BESS, Arizona (USA)	2019	Electrical anomaly leading to thermal runaway and accumulation of flammable gases inside container	Explosion during emergency response; multiple responder injuries	Critical need for gas detection (H_2, CO, volatile organic compounds or VOCs), proper ventilation, and safe emergency response protocols (delayed entry, monitoring before access)
Moss Landing BESS, California (USA)	2021–22	System-level failure and thermal event linked to integration/ design issues	Fire, smoke emissions, environmental concerns, temporary shutdown of large facility	Importance of system-level safety validation, design integration checks, and environmental risk management
San Diego (Gateway) BESS, California (USA)	2024	Thermal runaway with insufficient cooling and residual heat within cells	Fire persisted ~17 days with repeated re-ignition	Necessity of long-duration cooling strategies, re-ignition monitoring, and enhanced firefighting protocols for large-scale systems

As a result, international best practices now emphasize system-level validation through structured, multi-tiered testing.

A harmonized safety framework spans:

» Cell level: Mechanical (e.g., crush, penetration), thermal (e.g., heating, fire exposure), and electrical (e.g., overcharge, short circuit) conditions, along with off-gas characterization under IEC 62619.[6]

» Module/pack level: Propagation resistance evaluation under UL 1973.[7]

4 Details available at < https://neveragainmosslanding.org/wp-content/uploads/2025/03/Toxic-fluoride-gas-emissions-from-lithium-ion-battery-fires-PMC.pdf>

5 Details available at < https://cleanpower.org/wp-content/uploads/gateway/2025/03/Assessment-of-Potential-Impacts-of-Fires-at-BESS-Facilities.pdf>

6 IEC. Details available at <https://webstore.iec.ch/en/publication/64073>

7 UL 1973: Batteries for Use in Stationary and Motive Auxiliary Power Applications. Details available at https://energylibrary.tesla.com/docs/Public/EnergyStorage/Powerwall/General/Compliance/SafetyStandardsLithiumIonElectrochemical/en-us/GUID-BA00C1A1-25D7-4404-8308-58BA018B9AEC.html"

» Container/system level: UL 9540 system certification supplemented by UL 9540A* thermal runaway propagation testing, covering cell to installation scale fire and explosion behaviour.[8]

» Installation level: NFPA 855 (2026 edition), which links siting, spacing, gas detection, ventilation, suppression, and emergency response requirements to large- scale fire test evidence.[9]

For emerging markets with expanding RE and storage capacity, adopting science based, harmonized testing and certification pathways is essential. Integrating design stage hazard analysis, validated propagation testing, engineered thermal and gas management strategies, and clear emergency response protocols will ensure safer, scalable, and globally aligned deployment of MW scale BESS.

Figure 2 illustrates the global standards landscape governing BESS, covering cell-level safety, power conversion equipment, thermal management, transportation, installation codes, and fire explosion protection.

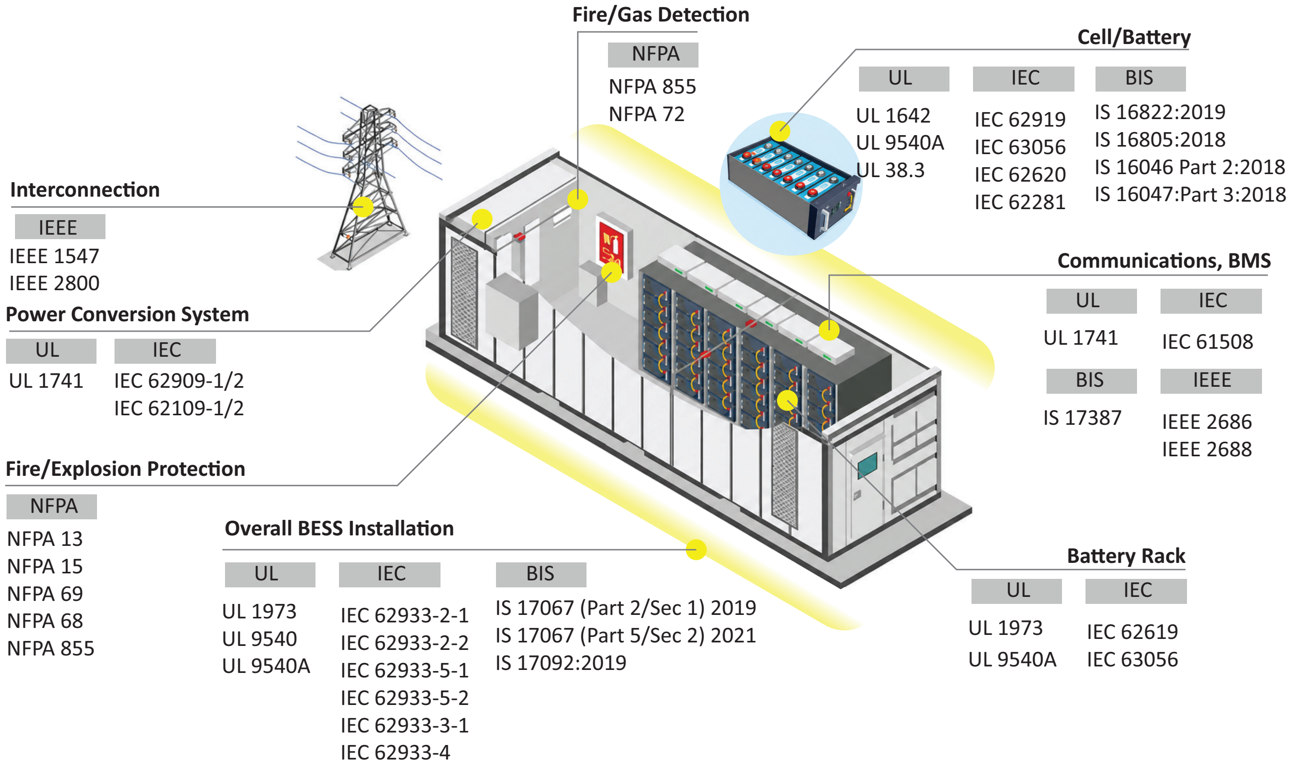


Figure 2 BESS standards and safety coverage

[8] UL 9540A Test Method for Battery Energy Storage Systems (BESS) | UL Solutions. Details available at <https://www.ul.com/services/ul-9540a-test-method>

[9] NFPA 855 Standard Development. Details available at <https://www.nfpa.org/codes-and-standards/nfpa-855-standard-development/855>

* UL 9540A is a test method, not a certification. UL 9540 (system certification) requires but does not replace UL 9540A test results

2. Safety Concerns in MW Scale BESS

As containerized BESS designs in 2024–25 have surpassed the 6 MWh threshold, with Original Equipment Manufacturer (OEM) releasing 6–6.5 MWh 20 feet and 40 feet container formats. System energy density has therefore reached record.[10] This trend has raised the bar for propagation control, off gas management, spacing, and responder safety in 2026 deployments.[11] In particular, the following have emerged as the major safety concerns for deployments, each of which requires dedicated design, testing, and operational controls:

A. Thermal and chemical hazards

Thermal runaway remains the primary initiating hazard in Li–ion BESS, triggered by internal shorts, over charge/ over discharge, mechanical damage, manufacturing defects, or local overheating; once initiated, self-heating accelerates, driving rapid temperature rise, pressure build up, and venting of flammable (e.g., CO, H_2) and toxic species (notably HF and POF_3). Full-scale tests quantify HF at ~20-200 mg/Wh,[4] underscoring the need for engineered ventilation and gas detection in enclosed utility scale units; water mist can increase the rate of HF formation even if the total is unchanged. UL 9540A 2025 adds explicit hydrogen measurement at the unit level, recognizing this ignition risk in modern, dense containers.

B. Electrical safety risks

The MW-scale BESS operate at high DC voltages often 1,000–1,500 V introducing significant electrical hazards. Key risks include DC arc faults, cable or busbar insulation failures, inverter/Power Conversion System (PCS) malfunctions, grounding faults, and Battery Management System (BMS) failure modes. Unlike AC, DC arcs do not self-extinguish, allowing sustained plasma arcs capable of igniting nearby materials. If a BMS fails to isolate a malfunctioning cell block or module, local electrical anomalies can escalate into full container thermal events.

The 2019 Surprise, Arizona BESS explosion illustrates this electrical, chemical coupling. After an initial electrical anomaly, the container accumulated flammable gases that ignited when responders opened the enclosure, causing a violent explosion and multiple injuries. The event exposed gaps in gas detection, electrical isolation, and emergency communication. It became a foundational case influencing global updates to fire codes, operational procedures, and enclosure ventilation requirements for MW-scale systems.[12]

[10] Understanding the Energy Capacity and Applications of BESS Containers. Details available at <https://www.tls-containers.com/tls-blog/understanding-the-energy-capacity-and-applications-of-bess-containers-tls-energy>

[11] UL Solutions. Details available at <https://delivery-p133222-e1298791.adobeaemcloud.com/adobe/assets/urn:aaid:aem:821fe510-78a0-4ed8-a94e-8eca8bc000cd/original/as/UL-000009-EIA_-_Industrial_Battery_-_E-Book_-_Inside_Look_-_UL_9540A_Final_Interactive.pdf>

[12] ioKinetic. Details available at <https://www.iokinetic.com/resources/articles/2025/12/09/battery-thermal-runaway-in-surprise-arizona>

C. Fire safety and emergency response

Li–ion BESS fires differ fundamentally from traditional hydrocarbon fires. They can burn for prolonged durations, undergo multiple re-ignition cycles, and continue producing flammable gases long after the initial event. Suppression approaches must therefore focus on sustained cooling, effective ventilation, and preventing re-ignition not only immediate flame knockdown. Conventional gaseous systems often prove inadequate because they do not remove heat from deep within cells.

A notable example beyond Moss Landing, California is the 2024 San Diego BESS fire, which burned intermittently for 17 days. Despite early suppression attempts, residual heat within compromised cells led to repeated re-ignitions until large volume water cooling was applied.[13] The case underscored that large-scale thermal mass in today's multi-MWh containers can support smouldering and re-ignition for days without aggressive cooling interventions. Similar, events have led to greater emphasis on firefighter training, remote- isolation protocols, real-time container gas monitoring, thermal imaging, and extended cool down procedures aligned with UL 9540A informed risk assessments.

D. Environmental and siting risks

Environmental exposure significantly affects BESS reliability and safety. High-ambient temperatures reduce thermal headroom, humidity ingress can cause insulation failure or corrosion, and dust or salt spray can impair cooling pathways or accelerate material degradation. Flooding and seismic risks present structural and electrical hazards, particularly for containerized systems deployed at ground level.

The Moss Landing incidents demonstrated that environmental and community impacts extend beyond facility boundaries. Smoke and particulate emissions prompted wide area air quality monitoring and community advisories. As a result, siting criteria in many jurisdictions have expanded to incorporate buffer distances, environmental impact assessments, emergency response accessibility, and requirements for atmospheric monitoring of metal aerosols and toxic gases following an event.

E. Operational and lifecycle safety

Safety risk evolves across the BESS lifecycle. As cells age, internal resistance increases, thermal response degrades, and abuse tolerance declines. Ageing can also create State of Charge (SOC) imbalances and increase susceptibility to internal shorts. Firmware errors, missed alarms, delayed BMS responses, or inadequate preventive maintenance can allow developing faults to remain undetected. Second-life batteries introduce additional uncertainty due to varied degradation histories.

Modern Operations and Maintenance (O&M) practices now emphasize continuous health monitoring, periodic thermal imaging, cell balancing, firmware verification, detailed commissioning/acceptance testing, and long-term data traceability (cell genealogy, cycle counts, maintenance logs). Incident analysis worldwide consistently shows that rigorous O&M procedures and real-time data analytics are among the strongest predictors of safe long-term operation in high-capacity systems.

[13] Details available at <https://www.wecc.org/sites/default/files/documents/progress_report2025>

3. Global Best Practices and Indian Context for BESS Safety

Overview of Global Standards for BESS Safety

The global standards ecosystem for Battery Energy Storage Systems (BESS) has evolved into a multi-layered safety framework spanning the entire technology hierarchy from individual cells to fully integrated, grid connected systems. Each layer introduces distinct risks:

- **Cell and module level:** Chemical stability, abuse tolerance, electrical protection, thermal stability, thermal runaway propagation, mechanical integrity, gas/venting management, and cell balancing/ Battery Management System (BMS) reliability.
- **Rack and container level**: System integration behaviour, gas management performance, fire detection and suppression, electrical fault and arc-flash protection, Heating, Ventilation, and Air-Conditioning (HVAC) reliability, control and protection coordination, environmental ingress protection, and maintenance safety.
- **Installation level:** Siting, ventilation, hazard mitigation, emergency response readiness, firefighting access, environmental exposure, electrical protection coordination, physical security, drainage/flooding protection, lightning protection, and maintenance readiness.

As BESS deployments scale into multi-megawatt configurations with increasingly dense energy architectures, international best practice frameworks emphasize the need for coordinated, system-level safety validation, rather than relying solely on component level compliance.

Global standards bodies including Underwriters Laboratories (UL), International Electrotechnical Commission(IEC), Institute of Electrical and Electronics Engineers(IEEE) and National Fire Protection Association (NFPA) have developed complementary standards that collectively address intrinsic battery safety, system integration, power electronics interoperability, environmental durability, fire and explosion protection, and installation requirements. Together, these standards establish a structured pathway for evaluating:

- how batteries behave under fault conditions,
- how systems prevent or contain thermal runaway propagation, and
- how installation-level measures protect personnel, infrastructure, and neighbouring communities.

Table 2 summarizes the principal international standards governing BESS safety along with their Indian counterparts, providing a consolidated reference for assessing alignment with global best practices.

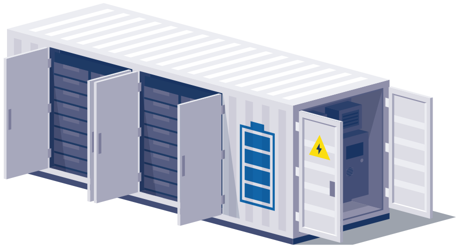


Table 2 Global best practice standards for BESS

Category	Key international standards	Indian equivalent	Bestpractice focus
Cell and module safety	UL 1642, UL 1973, IEC 62619:2022, IEC 63056:2020, UN 38.3, IEC 62281	IS 16805:2018	Safe operation of Li–ion cells/ modules; abuse testing; transport certification; industrial battery safety
BMS and electronics	IEC 61850, DNP3, UL 1998, UL 991, IEC 61508, IEC/UL 607301, EMC standards (IEC 6100062, IEC 61000-46)	IS 17387:2020 (BMS); IS 61850 (EMC)	Functional safety, secure communication, cybersecure controls, immunity to electromagnetic interference (EMI), programmable electronics safety
PCS/power conversion	IEC 62116, UL 1741/1741SB, IEEE 1547, IEC 621091/2, IEC 62116, IEC 61727, IEC 60068	IS 16169:2014. IS 9000-3-1 TO 5	Antiislanding, inverter safety, gridinterconnection compliance, environmental robustness
Environmental testing	IEC 6006821 (cold), IEC 6006822 (dry heat), IEC 60068214 (thermal shock), IEC 60068230 (humidity cycling)	IS 9000 series (based on IEC 60068)	Verifies performance under extremes of heat, cold, humidity, thermal cycling, and environmental stress
Systemlevel standards	UL 9540,IEC 6293351:2024, IEC 6293352:2025	IS 17092 (based on UL 9540); IS 17067 (various sections based on IEC 62933)	Full system integration safety; thermal runaway propagation, risk assessment, gridintegration safety
Fire and explosion safety	NFPA 855, NFPA 68, NFPA 69, NFSC 607 (Korea)		Spacing, siting, deflagration venting, explosionprevention systems, emergency response and firesuppression design

Note If a developer chooses to pursue certification based on IEC standards, all applicable certifications across the relevant categories should be obtained under the IEC framework. Similarly, if the developer opts for UL-based certification, all applicable certifications should be obtained under the UL framework. A combination of IEC and UL certifications across different categories is generally not recommended, as maintaining consistency within a single certification framework helps ensure uniform compliance.

Installation-level Codes: India-specific Risk Modifiers

International installation-level standards such as NFPA 855, NFPA 68, and NFPA 69 provide foundational guidance on siting, ventilation, deflagration venting, explosion prevention, and emergency response for BESS. However, these codes were developed for US climatic, infrastructural, and emergency response environments.

For India, contextual modifications (risk modifiers: site-specific factors such as climatic, infrastructural, and operational conditions that influence hazard severity and system response) are essential to ensure real-world applicability. Indian deployment conditions are shaped by consistently high-ambient temperatures, intense heatwave periods, monsoon- driven humidity, heavy dust and particulate exposure, and coastal corrosion, all of which influence thermal behaviour, sensor reliability, ventilation performance, and enclosure durability. In addition, India's grid experiences more frequent voltage fluctuations, feeder switching events, and transient disturbances, increasing operational stress on power conversion system (PCS) and battery management system (BMS). The BESS installations are also often located in densely populated areas or remote renewable parks where specialized firefighting resources, HF/H_2 monitoring capabilities, and extended duration cooling equipment may be limited. These environmental, infrastructural, and demographic factors underscore the need to adapt international installation codes to Indian conditions rather than adopt them verbatim.

Distinction Between Component-level and System-level Safety Requirements

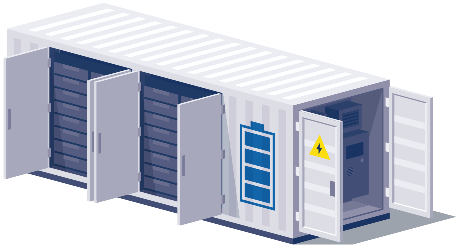
Safety considerations vary substantially across the BESS hierarchy cell, module, rack, and container and must be evaluated accordingly. Component-level standards address intrinsic battery behaviour, while system-level standards govern how these components interact under real-world operating conditions. To avoid conflating these two domains, the following tiered structure is adopted:

» **Cell/module safety**: Abuse testing, electrical protection, and thermal stability under standards such as IEC 62619 and UL 1973.

» **Rack/unit-level safety:** Thermal runaway propagation resistance, BMS logic integrity, and electrical isolation performance.

» **Container/system-level safety:** Full-scale fire propagation, off gas generation, siting, ventilation discharge direction, separation distance, firefighting access, drainage and flooding protection, lightning protection, and emergency-response readiness, deflagration behaviour, and integrated ventilation, evaluated through UL 9540A and UL 9540 system certification.

International experience consistently shows that component-level compliance alone does not guarantee system-level safety, especially in modern high-energy density utility-scale containers. A structured verification pathway linking all tiers is therefore essential to ensuring safe, predictable, and resilient operation across the entire BESS lifecycle.



Multi-tier Safety Validation Framework

Global BESS safety regimes follow a staged validation pathway to ensure traceability of risks across system boundaries. India's regulatory framework currently lists standards but lacks a consolidated verification map.

Recommended national validation pathway:

1. **Cell level:** Abuse tests, vent gas characterization (IEC 62619).
2. **Module level:** Propagation resistance, electrical isolation (UL 1973).
3. **Rack/Unit level:** Unit-scale thermal runaway, fire-suppression interaction, rack BMS logic, insulation monitoring, DC protection, fuse/contactor coordination, grounding, arc-flash risk, emergency disconnect provisions, and communication failure response (UL 9540A, Unit Test).
4. **Container level:** Full-scale destructive testing including off-gas, pressure rise, flame spread (UL 9540A, large-scale test).
5. **Installation level:** Spacing, ventilation, dispersion modelling, firefighting strategy, drainage and flooding protection, lightning protection, earthing design, separation from occupied buildings, emergency isolation (NFPA 855, hazard mitigation analysis).

This structured hierarchy must be adopted in Indian tendering and regulatory processes.

Best Practices for Containerized BESS

With 20-feet containers now exceeding 6–6.5 MWh in commercial deployments, best practices must address the intensified consequences of failure. Table 5 lists the global best practices adopted for the containerized BESS.

Table 3 Global best practices for high-density (6-6.5 MWh) containerized BESS

Best practice area	Recommended practice	Rationale /evidence
Factory built standardized containers	Use preassembled, precommissioned 20ft/40ft BESS containers built and tested to UL 9540 + UL 9540A	Reduces wiring errors and integration faults; highdensity 6–6.5 MWh systems already shipped globally (Lingtech 6.25 MWh; Cygni 6.25 MWh; SolarMD 6.5 MWh)
Compartmentalization/ internal fire protection	Use rack level segmentation, thermal barriers and module spacing aligned with UL 9540A propagation hierarchy	UL 9540A requires evaluating thermal runaway(TR) propagation cell→ module→ unit→ installation; segmentation reduces cascading failures
Fire detection and suppression	Early smoke/heat detection (VESDA + temperature sensors), automatic isolation, and prolonged waterbased cooling	Fires in San Diego (Gateway) burned 17 days, showing clean agents alone cannot stop deepseated TR. Moss Landing events show smoke/offgas requiring emergency responses.

Contd...

Table 3 *contd...*

Best practice area	Recommended practice	Rationale /evidence
Gas detection and ventilation	Install H_2, CO, VOC, HF detectors and active ventilation sized to maintain concentrations below lower flammability limit (LFL)	UL 9540A data shows HF emissions of 20-200 mg/Wh; NFPA 855 (2026) requires ventilation & explosionprevention integrated with UL 9540A installationlevel results.
BMS supervision and rogue module isolation	Requires redundant sensing, faultisolation logic, firmware validation, and rapid isolation of abnormal modules	Arizona Public Service(APS)/McMicken investigation shows delayed isolation → TR propagation → flammable gas buildup → deflagration injuring responders
Factory safety validation (Failure Modes and Effects Analysis(FMEA)+ Hazard and Operability Study(HAZOP))	Conduct design FMEA, process FMEA, and HAZOP before FAT	Ensures early detection of design or manufacturing faults before container assembly
Traceability of cell genealogy	Track cell manufacturing batches, genealogy mapping, and ageing profiles	Incident investigations (APS, Moss Landing) show genealogy tracing is essential for root-cause analysis
Factory acceptance testing (FAT)	FAT must verify wiring, insulation, thermal performance, BMS/EMS logic, gasdetection calibration	Aligns with UL 9540 system integration requirements and NFPA 855 commissioning expectations
Site level infrastructure	Follow NFPA 855 spacing and hazardmitigation analysis (HMA), UL 9540A data for gas dispersion, ensure drainage, access routes, remote isolation	Moss Landing and San Diego events required evacuations, plume monitoring, and largescale emergency response highlighting siting and publicsafety needs
High voltage DC electrical safety	Evaluate DC arc hazards at 1,000-1,500 V DC; implement guarded terminations, personal protective equipment (PPE,) maintenance protocols	DC arc faults persist without zerocrossing; common triggers include insulation breakdowns and loose terminations
Operations, monitoring, reignition management	Continuous thermal monitoring, infrared inspections (IR) inspections, remote gas monitoring, extended cooldown monitoring	Elkhorn Megapack burned ~6 hours + vented smoke ~12 hours; gateway fire reignited over multiple days longduration events require extended monitoring

UL 9540A (2026) Updates: Strengthening BESS Safety and Its Implications for India

The latest 2026 revision of UL 9540A building on prior advancements, introduces several significant enhancements that strengthen the accuracy, applicability, and installation-level usability of thermal runaway test data. These updates improve the evaluation of fire, explosion, and gas-related risks in BESS, particularly under real-world operating conditions.

Key updates include:

a. Clear separation of fire hazard evaluation from explosion/deflagration hazard assessment, enabling independent analysis of thermal propagation and gas-phase risks, including hydrogen-related hazards.

b. Revised installation-level test methodologies to ensure robust fire initiation, leading to credible worst-case fire scenarios.

c. Indoor test configurations now require sprinkler systems to be evaluated under the most challenging operating conditions, ensuring conservative validation of fire- suppression effectiveness.

d. Introduction of Large Scale Fire Testing (LSFT) at the installation level (aligned with NFPA 855), as an additional requirement alongside existing cell-, module-, and unit-level tests.

e. LSFT is designed to simulate actual installed conditions of a BESS, including associated equipment, enclosures, and structural arrangements.

These updates are particularly relevant for India, where next-generation high-density BESS containers (6–6.5 MWh) are being deployed. Such systems exhibit elevated risks, including hydrogen accumulation, fire propagation, and siting constraints in densely populated or high-temperature environments.

Key objectives of LSFT include:

» Assessing thermal exposure under fully developed fire scenarios within the BESS system and the risk of propagation to adjacent or nearby BESS stacks.

» Evaluating the potential for fire ignition in adjacent structures.

» Verifying the effectiveness of the proposed fire protection strategy in limiting fire propagation.

» Supporting the determination of appropriate separation distances, as defined in UL 9540 assessments or manufacturer guidelines.

f. Installation-level testing is generally not required for aqueous-based battery chemistries such as lead–acid, nickel–cadmium, metal–air, nickel–zinc, and flow batteries or for systems where cell-level testing has demonstrated no risk of thermal runaway, and it is not applicable to BESS units or stacks intended for residential use.

4. Current Status in India

India's energy storage landscape is evolving rapidly, supported by multiple standards outlined under Bureau of Indian Standards (BIS), policy guidelines, and safety frameworks. However, compared to the United States / European Union, India's ecosystem is still fragmented, especially regarding containerized BESS and installation-level codes.

Overview of Indian Standards

India has established a growing set of BIS norms focused on battery safety, energy storage systems, and BMS functionality as mentioned in Table 2.

These standards ensure battery, pack, and system-level safety, but do not yet fully address containerized BESS fire propagation, explosion scenarios, or siting areas where UL 9540/9540A and NFPA 855 dominate internationally.

Existing Battery Testing Infrastructure in India

India has rapidly expanded its domestic testing capacity:

Key government supported testing facilities

» **NABL/BIS-**recognized labs conduct tests under IS 16046, IS 16270, IS 16893, and IS 17387.

» **Ministry of New and Renewable Energy (MNRE)/Ministry of Power (MoP) Draft Guidelines** (2025) indicate expansion of accredited labs for Solar Order 2025 battery testing.[14]

» **Central Electricity Authority (CEA)/ Central Electricity Regulatory Commission (CERC)/ State Electricity Regulatory Commissions (SERCs)** to grid and inter connection requirements National Disaster Management Authority (NDMA)/state fire services to emergency-response protocols.

[14] MNRE Issues Draft Guidelines for Storage Battery Testing and Approval. Details available at <https://www.mercomindia.com/mnre-issues-draft-guidelines-for-storage-battery-testing-and-approval>

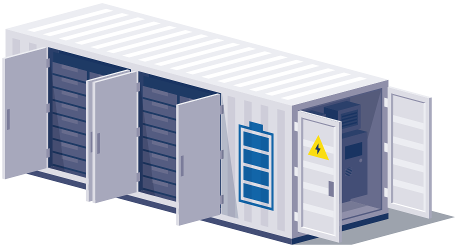


Table 4 Battery testing infrastructure in India

Testing lab	Capabilities	Key standards/tests supported
Central Power Research Institute (CPRI)	Testing of Li-ion, Lead–acid, Ni–Cd cells AND packs; up to 18 V/4,000 Ah and packs to 450 V/3,000 Ah; R&D in materials and cell fabrication	IS, IEC, BIS standards; performance, safety and R&D tests
Automotive Research Association of India (ARAI)	Battery test systems, BMS testing, abuse testing, electromagnetic compatibility (EMC), and electrical safety	Energy storage service(ESS) safety, environmental, and functional tests
TÜV NORD	Cell and pack testing; certification support	IS 16046, IS 16270, IS 15549, IEC 62133, IEC 60254, UN 38.3
Intertek India	Full lifecycle testing: performance, abuse, fire/thermal propagation, grid compliance; UL and IEC certification	UL9540/9540A/1973/9540B, IEC 62619, IEC 6293352, IEEE 1547
Société Générale de Surveillance (SGS)	Abuse testing, thermal stability, life cycle, EMC, functional safety	ISO 26262, EMC standards, IEC/IS battery standards
Bureau Veritas	BISrecognized lab for battery and photovoltaic (PV) component testing	BIS certification programmes
Semco Infratech	Supplies battery testing equipment for Indian labs	Test rigs for R&D, validation, and certification

From Table 4, it can be established, no Indian lab currently offers full-scale UL 9540A equivalent testing, i.e.,

» Cell to module to unit propagation tests

» Container level fire test with gas measurement (H_2, HF, CO)

» Installation-level evaluations

India's testing ecosystem is battery centric, not system centric, and lacks container fire testing infrastructure.

Key Gaps and Challenges

» **Technical gaps**

◊ No standardized testing methodology for containerized BESS

- UL 9540A style fire propagation, gas measurement, and deflagration tests are not available within India.
- Existing BIS standards (IS 17092, IS 16893) do not include container-scale thermal runaway propagation tests.
- The MNRE issued guidelines focus on cell and battery, not full container-level safety.

- **Regulatory gaps**
  - ◊ No unified national installation code for BESS
    - India lacks an equivalent to NFPA 855, which governs:
    - Siting and spacing
      - Gas ventilation
      - Fire detection/suppression
      - Emergency response
  - ◊ Installation requirements are scattered across:
    - IS 17092 (general ESS safety)
    - IS 16893 (planning and installation guidance)
    - CEA grid codes (inverter/PCS rules)
    - MNRE/MoP tender specific requirements
- **Capacity gaps**
  - ◊ Need for training of utilities, engineering, procurement, and construction companies(EPCs), distribution companies(DISCOMs,) and emergency responders
  - ◊ Real-world incident learnings (e.g., McMicken and Moss Landing globally) show how lack of preparedness can lead to unsafe entry, mismanaged suppression, and high responder risk, Indian responders currently lack standardized ESS training programmes.

[15] Energy Storage Systems(ESS) Policies and Guidelines. Ministry of New and Renewable Energy, India. Details available at <https://mnre.gov.in/en/energy-storage-systemsess-policies-and-guidelines/>

5. Recommendations and Way Forward

India's rapid push towards 500 GW renewable energy by 2030[16] and national Battery Energy Storage target requires a coordinated national road map covering standards, infrastructure, regulation, capacity building, and industry incentives.

The following recommendations directly respond to the identified gaps in India's current ecosystem:

A. Regulatory and standards road map

» Mandate UL 9540A equivalent testing for all MW-scale BESS:

◊ UL 9540A equivalent testing in India adopts a clearly defined, multi-tier structure encompassing: cell, module, unit (rack/container), and installation-level hazard analysis. Each stage yields unique and indispensable safety evidence, and comprehensive system assurance can only be achieved when all tiers are evaluated in sequence.

◊ Require UL 9540A equivalent thermal runaway propagation testing for BESS project receiving government subsidy, viability gap funding (VGF), or accelerated permitting.

◊ Align BIS standards with IEC 62933-5-2 (ESS safety) and incorporate UL 9540A style large- scale testing for Indian conditions.

This can be implemented through direct adoption of UL 9540A, development of an India-specific aligned protocol, and interim reliance on accredited international test evidence until national testing infrastructure is operational.

» Develop a national BESS safety and installation code

It is recommended to consolidate existing BIS standards (IS 17092, IS 16893) into a single, India-specific installation, and safety code that reflects both international best practices and domestic operating conditions. The code should:

◊ Integrate NFPA 855 aligned spacing and siting requirements, through UL 9540A installation-level safety data.

◊ Incorporate gas-dispersion modelling for critical species such as H_2 and HF.

◊ Define firefighter and responder safety envelopes, including access pathways and emergency isolation zones.

◊ Mandate HAZOP during the design stage to identify systemic and integration risks early.

◊ Define site acceptance testing (SAT) to verify that installed systems meet design stage safety assumptions.

This harmonized code should serve as the single national reference for the safe siting, installation, and commissioning of BESS assets across India.

---

[16] Details available at <https://www.pib.gov.in/PressReleasePage.aspx?PRID=1795071&reg=48&lang=2>

» Operational blueprint for policy and tender implementation

To enable ministries and procurement bodies to operationalize safety requirements, the following actionable blueprint is recommended:

» Define mandatory test levels (cell, module, unit, container).

» Prescribe minimum test reporting formats based on UL 9540A matrices.

» Integrate installation-level analysis (ventilation, spacing, responder access) into Technical Bid Part I.

» Require functional safety and cybersecurity certification for BMS/EMS.

» Mandate Site Acceptance Testing (SAT) to verify as installed systems.

» Tender documents should maintain a consistent list of required standards and certifications across all projects, while permitting location specific safety requirements (e.g., climatic, hazard zone, or grid integration conditions).

B. Infrastructure development

Establish a national fire and propagation test bed:

» A government-backed lab capable of full-scale destructive testing of MW-scale containerized BESS.

» Strategic collaborations with international testing agencies should be encouraged to establish UL 9540A equivalent and container-scale testing infrastructure within India.

» Supports BIS development for next generation ESS standards, especially as India accelerates storage deployment.

» BIS should increase the number of accredited labs and improve industry access to reduce certification bottlenecks and accelerate market participation.

C. Functional safety and cybersecurity requirements for BESS

India must meet the following requirements:

» BMS functional safety certification (IEC 61508, UL 1998)

» EMS/PPC fail-safe logic validation

» Cybersecurity compliance (IEC 62351, IEC 62443)

D. Capacity building

Launch a national BESS safety curriculum, training modules for distribution companies (DISCOMs), state load dispatch centres (SLDCs), engineering, procurement, and construction (EPC) contractors, and private developers on:

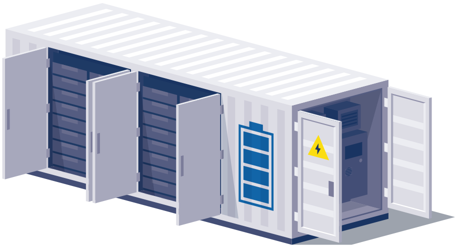
» ESS hazard identification

» BMS fault response protocols

» High voltage DC safety

» Operational monitoring and failure diagnostics

Create a mandatory certification for BESS commissioning engineers.



E. First responder training programme for state fire services

India must adopt Li–ion-specific fire protocols like global best practices, standard operating procedures (SOPs) should include:

» Container entry restrictions

» Gas (H_2 /HF) monitoring

» Long-duration cooling tactics

» Safe re-entry thresholds based on LFLs and thermal imaging.

» HF exposure protocols

» Respiratory PPE requirements for high-toxicity environments

» Gas dilution threshold values (UL 9540A output)

» Thermal imaging training for re-ignition prediction

» National agencies should establish a standardized emergency response plan (ERP) tailored to LFP and other chemistries, covering hazard identification, gas management, isolation protocols, and re ignition monitoring.

F. Industry development and market support

Incentivize Indian manufacturing of certified BESS containers

» Provide capital subsidies/Production-linked Incentive (PLI) add-ons for manufacturers meeting UL 9540/ UL 9540A / IEC 62933 compliance.

» Provide support to extend domestic testing infrastructure development, certification ecosystem strengthening, and skilled manpower creation.

» Promote component localization, fire-safe container design, and indigenous BMS/EMS development, along with safety-focused manufacturing quality assurance practices.

G. Battery circularity and sustainability

The circularity framework for Li–ion batteries is highly relevant for India's BESS sector, which is rapidly scaling. The four-stage framework (ecological design → manufacturing and use → end of life → recovery) essentially maps out India's road map: while the country is currently most active in the manufacturing and use phase, driven by hybrid renewable tenders and the government's energy storage obligations, the end of life and recovery stages are where strategic value is being left on the table.

UL 3601 is a global standard for measuring and reporting how circular a Li–ion battery is covering its entire life from production to recycling ensuring transparency and comparability across manufacturers.

For India, key initiatives should be:

» Adopt UL 3601 under Bureau of Indian Standards to create an India-specific circularity reporting norm for BESS projects.

» Ministry of New and Renewable Energy (MNRE)/Solar Energy Corporation of India Limited (SECI) should include a battery circularity score as an evaluation parameter in project tenders.

» Integrate UL 3601 metrics into India's existing Central Pollution Control Board (CPCB) - Extended Producer Responsibility (EPR) tracking system for real-time lifecycle data.

GIZ
Deutsche Gesellschaft für
Internationale Zusammenarbeit GmbH
B-5/5, Safdarjung Enclave,
New Delhi, 110029, India
T: + 91 11 49495353 | E: info@giz.de | W: www.giz.de/India

The Energy and Resources Institute (TERI)
Darbari Seth Block, Core 6C,
India Habitat Centre, Lodhi Road,
New Delhi - 110 003, India
Tel: (+91 11) 2468 2100, 7110 2100
Email: mailbox@teri.res.in