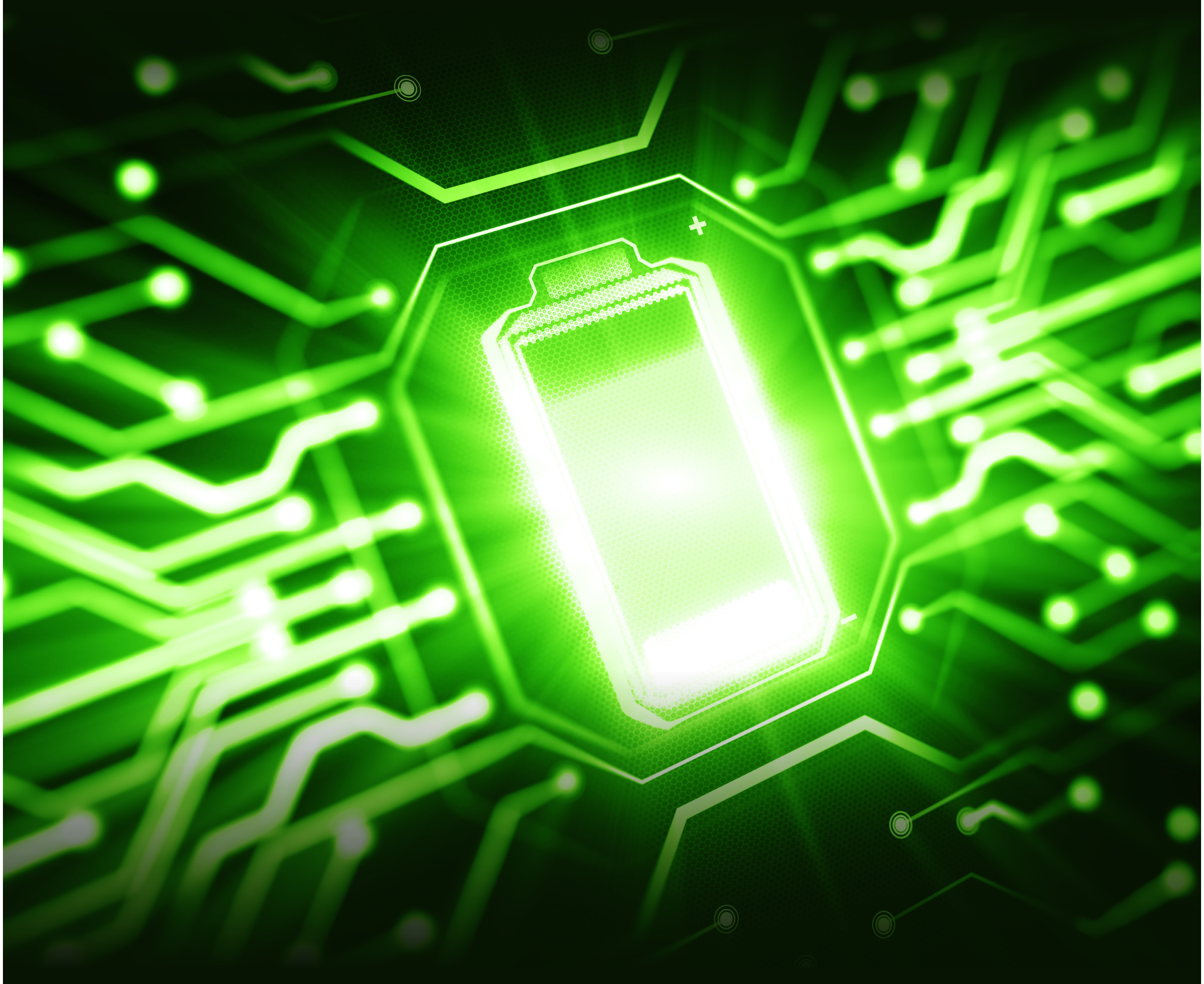
Global Overview of Energy Storage Performance Test Protocols



An Energy Storage Partnership Report

NREL
Transforming ENERGY

Global Overview of Energy Storage Performance Test Protocols

This report of the Energy Storage Partnership is prepared by the National Renewable Energy Laboratory (NREL) in collaboration with the World Bank Energy Sector Management Assistance Program (ESMAP), the Faraday Institute, and the Belgian Energy Research Alliance.

Nate Blair, Andrew Schiek, Anthony Burrell, Matthew Keyser - NREL

Andrew Deadman, Ian Ellerington – Faraday Institute

Leen Govaerts, Grietus Mulder, Patrick Hendrick, Thomas Polfliet –
The Belgian Energy Research Alliance

Phillip Hannam, Chong Suk Song – The World Bank ESMAP

Technical Report
NREL/TP-6A20-77621
Revised March 2021

NOTICE

This work was authored, in part, by the National Renewable Energy Laboratory (NREL), operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the Children's Investment Fund Foundation (CIFF) under Contract No. ACT-17-00031. The views expressed in this report do not necessarily represent the views of the DOE or the U.S. Government, or any agency thereof.

NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency & Renewable Energy Operated by the Alliance for Sustainable Energy, LLC. This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.
Contract No. DE-AC36-08GO28308

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 - www.nrel.gov

Errata

As a global product shared within and beyond the World Bank Energy Storage Partnership, subsequent information was offered to the author team after the original release of this publication, which the author team had been unable to discover previously regarding standards in China (Section 4.2). The addition of this information augments the report and improves the experience for the reader.

Acknowledgments

This document is a result of the efforts of Working Group 3 of the World Bank Energy Storage Partnership. The key organizational members of this working group are:

- National Renewable Energy Laboratory:
  - Andrew Schiek
  - Nate Blair
  - Tony Burrell
  - Matt Keyser
- Faraday Institution:
  - Ian Ellerington
  - Andrew Deadman
- The Belgian Energy Research Alliance:
  - Leen Govaerts
  - Grietus Mulder
  - Patrick Hendrick
  - Thomas Polfliet.

Additionally, from the World Bank, several key staff have been engaged with the working group and this report, including Manuel Jose Millian Sanchez, Fernando de Sisternes, Chong Suk Song, and Phil Hannam. The working group also thanks the broader Energy Storage Partnership team for any comments and feedback from other working groups as well.

List of Acronyms

EES	electric energy storage
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Standardisation Organisation
PNNL	Pacific Northwest National Laboratory
PV	photovoltaic
SOC	state of charge
UL	Underwriter's Laboratory

Table of Contents

List of Figures

1 Introduction and Objectives

As part of the World Bank Energy Storage Partnership, this document seeks to provide support and knowledge to a set of stakeholders across the developing world as we all seek to analyze the emerging opportunities and technologies for energy storage in the electric sector. As global prices for renewable energy have dropped dramatically over the last decade and continue to decline and the value of energy storage has increased in many systems, the World Bank technical teams and others have been hearing of a variety of problems, including:

- Potential lack of quality across battery technology providers that are sometimes difficult to determine initially
- The use cases for energy storage are nonobvious and complex, particularly for the broad range of electric system configurations in developing countries. Different technologies respond to those use cases differently, and so testing is needed for many of these use cases and often in the country where the storage will be deployed at scale. Compounding this issue, planners are not used to incorporating energy storage and are uncertain as to what they need and how they will use the storage assets they acquire.
- A variety of battery storage is currently designed for consumer electronics or for vehicle usage. Like the issue above, grid storage conditions can be quite different than the conditions for use in vehicle transportation, which might mean that a different technology actually could be the preferred stationary storage technology.
- It seems that on an almost daily basis, a new storage technology is announced as the breakthrough we have all been waiting for with both significant funding and an appealing potential. These emerging technologies (gravity, liquid air, geothermal, thermal) do not have testing standards or commissioning protocols.

Related, developing countries have been asking a series of questions in this new area, including:

- Which technology should be used?
- Which suppliers to use?
- How can we confirm that the quality and lifetime are as good as the manufacturer says?
- If we want some samples tested, where can we go?
- If we want to set up our own testing center, how do we go about doing that?

This working group seeks to address the issues raised in part by creating this document and by gathering a variety of experts in this area from across the globe in support of the World Bank efforts. Performance testing, in combination with test beds (Working Group 2), is critical to fulfill the promise offered by these breakthrough technologies and critical to increasing trust in these systems and reducing risk.

Finally, and importantly, the rapid changes and emerging companies and technologies mean that there is a very minimal history for any company in the area of energy storage. Recent economic uncertainty has shown that even companies with good reputations might leave the market unexpectedly. There are no broad industry leaders and even if the companies are consistent, their products are changing rapidly. These market dynamics are similar to the market dynamics of the early explosion of the photovoltaic (PV) market in the years around 2010. The market was exploding, and costs were plummeting resulting in many different manufacturers, uneven quality, and higher levels of risk that a procurement could result in PV panels that did not perform as expected. Over time, the industry continued to grow, quality has improved significantly, and differentiation and precision in product offerings has dramatically reduced the risk inherent in procuring PV modules. These similar trends in the energy storage industry will similarly likely dissipate over time as the technology and manufacturers continue to mature. While that process unfolds, the need for both component and system testing across a range of use cases is critical.

2 The Role of Energy Storage Testing Across Storage Market Development (Best Practices for Establishing a Testing Laboratory)

This section of the report discusses the architecture of testing/protocols/facilities that are needed to support energy storage from lab (readiness assessment of pre-market systems) to grid deployment (commissioning and performance testing). It does this by summarizing international literature and reports as well as summarizing testing software and energy storage analysis software more broadly.

2.1 Good Practices with Storage Systems.

The issue of how to install, use, and decommission a storage system is now happening very regularly and has been documented by both international and national task groups. Such analysis contains a part with general validity and a part that is dependent on the local system, including the availability of an electricity grid, the reliability of the grid, the share of renewables in the grid, multi-benefit solutions, but also weather conditions that require specific storage housing (such as requiring the system being a meter above ground level for potential flooding). Unfortunately, reports by national task forces are written mostly in the local language, making them more difficult to find—but translation software can be helpful once found.

Below is a non-exhaustive list of valuable reports that the working group has relied on when becoming familiar with storage testing.

2.1.1 International Reports

"Electric energy storage – future storage demand" by International Energy Agency (IEA) Annex ECES 26, 2015, C. Doetsch, B. Droste-Franke, G. Mulder, Y. Scholz, M. Perrin.

Despite the future demand in the title, this is a fraction of the total contents. The extensive report gives insight into the technical and economic framework for electric energy storage systems in the first 50 pages. It also contains an overview of all applications, based on a meta-analysis of other studies, such as those from Sandia and the Electric Power Research Institute. The report discusses the other system options besides storage such as demand side management and voltage support by inverters. These alternatives are explained. Testing the storage is an important section (40 pages are dedicated to it), covering technological dependent tests as well as application dependent test methods. For more information, see http://dx.doi.org/10.24406/UMSICHT-N-484738.

"European White Book on Grid-Connected Storage," DER-Lab, 2012

The distributed energy resource lab is a consortium of European laboratories for distributed energy sources. They publish white books regularly. This white book focuses on storage systems as seen from the grid (including converters), rather than on the storage technologies. Issues such as technical requirements, especially interconnection issues, tariff structures, and, more generally, economic aspects, test procedures for selecting storage, , are covered. For the report, see https://der-lab.net/wp-content/uploads/2017/03/noe_003_grid_connected_storage.pdf.

BatteryStandards.info

This website is the fruit of collaborations between European research projects and continues to be updated. As the name implies, it focuses on standards for batteries. This information is given as a literature overview, as tables with test standards and comparison of test conditions, as well as a database with standards:
https://www.batterystandards.info/

"Annex Analysis of available relevant performance standards & methods in relation to Ecodesign Regulation for batteries and identification of gaps," VITO& JRC, 2019
This report gives an overview of standardization activities by technical committees and short contents of battery standards, as well as comparative tables. Find the report at:
http://ecodesignbatteries.eu/sites/ecodesignbatteries.eu/files/attachments/ED_Battery_Annex_Standards_V11_0.pdf.

2.1.2 National Reports

A Good Practice Guide on Electrical Energy Storage, EA Technologies, 2017, United Kingdom

This report is based on individual project outputs exchanged within the Energy Storage Operators' Forum in the United Kingdom. The Guide is designed as a reference document, with chapters relating to each stage of the project life cycle (e.g., procurement, installation, safety assessment, business case development). It also introduces various electrical energy storage technologies and the ways in which they can be used. Eighteen detailed case studies are provided, covering each distribution network operator storage project and a selection of the demonstration projects funded by Department of Energy & Climate Change. For more information, see https://www.eatechnology.com/engineering-projects/electrical-energy-storage/.

"Battery Install Guidelines for Accredited Installers," Clean Energy Council, 2017, Australia

This guideline was developed by the Clean Energy Council to fill the gap in Australian standards regarding the installation of battery energy storage devices in 2017. The involved hazards are covered, and the possible mitigation is dealt with. See
https://assets.cleanenergycouncil.org.au/documents/accreditation/battery-installation-guidelines-2017.pdf.

"D7.5 Methodology report for application specific design of BESS", CEA, H2020 Osmose project, 2020.

This report develops methods and associated tools to optimize the design of battery electric storage systems by considering both the application and the storage performance over its lifetime. See https://www.osmose-h2020.eu/downloads/#.

2.2 Energy Storage Analysis Software

Several applications are available to estimate the local need for storage. Such software can be a starting point before deliberating about specific storage solutions in a feasibility analysis section.

Some years ago, Pacific Northwest National Laboratory (PNNL) made an overview for the U.S. Department of Energy of software tools that include electric energy storage.[1] This American-centric report found 14 tools, while some of the dominant European-used tools were left off (such as Markal-Times). Future versions of this report will seek to provide an updated and more extensive list, but these tools will provide direction to the reader.
The PNNL study identified as non-commercial products:

- ReEDS https://www.nrel.gov/analysis/reeds/
- NEMS https://www.eia.gov/outlooks/aeo/nems/documentation/
- RETScreen https://www.nrcan.gc.ca/maps-tools-publications/tools/data-analysis-software-modelling/retscreen/7465
- EnergyPlus https://energyplus.net/
- Kermit https://www.dnvgl.com/services/software-tools-for-energy-storage-153084
- GridlabD https://www.gridlabd.org/.

The PNNL study identified as commercial products:

- Homer https://www.homerenergy.com
- GE Maps https://www.geenergyconsulting.com/practice-area/software-products/maps
- Ventyx System Optimiser/ProMod https://new.abb.com/enterprise-software/energy-portfolio-management/market-analysis/promod
- Power World https://www.powerworld.com/solutions/renewable-energy
- Energy 2020 https://www.energy2020.com/energy-2020
- Integrated Planning Model https://www.icf.com/technology/ipm
- Synergi. https://www.dnvgl.com/services/synergi-software-for-simulation-and-optimization--14642 A recent development is OSMOSE by CEA (France; see also report section above).

[1] Hoffman, M., Sadovsky, A., Kintner-Meyer, M., and DeSteese, J. 2010. *Analysis Tools for Sizing and Placement of Energy Storage in Grid Applications, A Literature Review*. Richland, WA: PNNL.

3 Background on Applicable Energy Storage Systems

This section provides background on some of the systems that will be discussed in future sections. The purpose of this section is to give the reader some necessary information on topics to be discussed. This in no way encompasses the full depth of each topic, but makes understanding future discussion easier.

3.1 Applicable Energy Storage Systems

There are four main energy storage systems that are addressed in this research: lead-acid, lithium-ion, sodium-sulfur, and flow batteries. Review of global market reports indicates that lead-acid and lithium-ion were the primary battery energy storage systems used, each has its own advantages and disadvantages. Lead-acid and lithium-ion were the most common batteries utilized, and between those two, lithium-ion energy storage systems tend to perform better than lead-acid at extreme conditions (particularly hot) and offer a longer life. Lead-acid batteries are less prone to thermal runaway, making them slightly safer. For more information on the comparison between these two types, see this article here: https://www.altenergymag.com/content.php?post_type=1884. Regarding the other types of batteries sodium-sulfur can be unsafe because they run at a high temperature and have toxic materials. Flow batteries are not energy-dense, so they take up more space. This may leave the reader wondering why one would choose sodium-sulfur or flow batteries, but in some instances, these may be the more economically viable option. There are many factors that go into the pricing; however, we will refrain from generalizing here. For more information on these types and a comparison to lithium-ion energy storage systems, see http://large.stanford.edu/courses/2016/ph240/smith-c1/.

3.2 Stationary Applications

There are several applications for stationary energy storage systems including:

- Frequency Regulation: One of the more important ones is frequency regulation. In frequency regulation applications, the frequency is adjusted based on the loads that are active and demanding variable power, as necessary. They provide “up” regulation by discharging and “down” regulation by charging.

- Peak Shaving: Another important application is peak shaving, where the energy storage system is discharged during and “on-peak” period and charged during an “off-peak” period.

- Voltage Support: This is also important and is where the power is used to maintain the voltage within specified limits.

- Phase Balancing: Phase balancing is the process of keeping the load at each phase as balanced or equal as possible.

- Energy Trading: Energy trading is where bulk energy is bought or sold and moved to an area of need.

- PV Smoothing: PV smoothing where power is added or taken away to mitigate large changes in the PV power output.

- Behind the meter storage: When energy is generated (usually from wind, solar, or heat) and stored until it is needed to be released but typically at an individual building and "behind the meter".

More details and applications can be found at these two sources: https://energymaterials.pnnl.gov/pdf/PNNL-22010Rev2.pdf and http://dx.doi.org/10.24406/UMSICHT-N-484738.

While PV smoothing is not cost-effective in all systems and particularly large well controlled systems, PV smoothing can be important in small grids or grids with limited automated control. The algorithm that helps PV smoothing determine how to shift the power load can vary, but essential to any algorithm is the ability to mitigate substantial changes. We will briefly discuss two examples provided by papers by Sandia National Laboratory. In the first example, they used Matlab/Simulink to simulate how using a battery can reduce the variability in PV power output. To track the PV power output, either the time moving average of the PV power or the PV power processed through, a low pass filter is used. For the moving average, a time window is used, and for the low pass filter, a time constant is used. The power output over the time duration is examined, and the battery is used to adjust for large changes. They set a minimum change for adjustment to not overwork the battery. The battery is also regularly kept at a state of charge (SOC) of 0.6 and is kept between 0.4 and 0.8 to not overwork the battery. The full paper can be found here: https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2012/121772.pdf.

In the other example, the authors look at a grid-tied PV system. Here, a battery is also used to provide or absorb power. As in the last example, the authors set bounds on the SOC and keep it in the middle of those bounds. The reason for this is, if the battery is fully charged, it cannot absorb any power, and if it is fully discharged, it cannot provide any power. In this case, solar irradiance is the other control on the system. They multiply the solar irradiance by a scale factor to delay and smooth the output power. The full paper can be found here: https://energy.sandia.gov/wp-content/gallery/uploads/PV-Energy-Smoothing.pdf#:~:text=Effective%20PV%20energy%20smoothing%20requires%20an%20energy%20storage,operate%20at%20a%20partial%20state%20of%20charge%20%28PSOC%29. An example of the results of the smoothing process is shown in Figure 1. From the results, while irradiance fluctuates significantly, the utility power climbs gradually, and does not experience significant, short-term spikes. In addition, the SOC of the two batteries used stays stable.

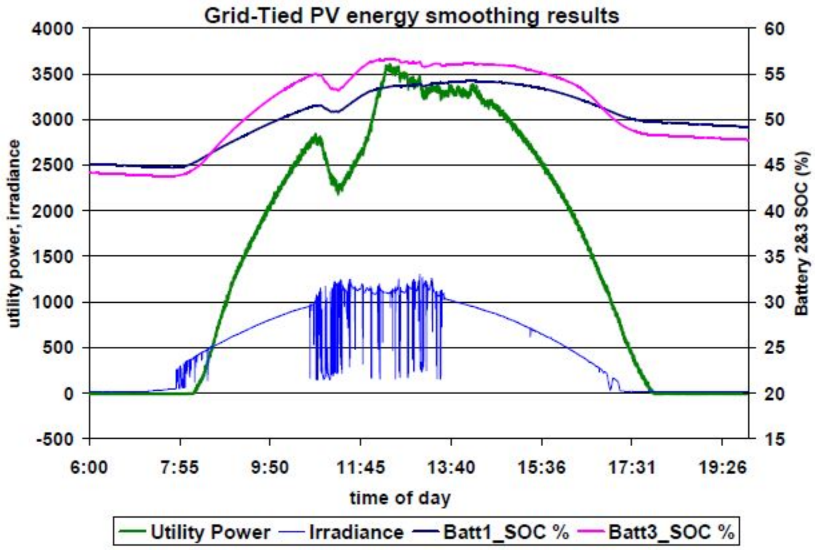


Figure 1. An Example of PV Smoothing Results

Between both examples, there are consistencies that can be applied. The overall goal is to limit spikes in the power output. A battery can be used to send or absorb power, but the SOC of the battery must be kept between reasonable bounds for it to be able to absorb or send power at any given time.

Some additional information on peak shaving is provided in a recent article in CSE Magazine. Similar to PV smoothing, a battery or energy storage system can be used with the grid. Here, the energy storage system is charged during low or "off" hours. During peak hours, the battery provides additional support to the energy storage system. This process can reduce the cost of providing energy, while also improving the quality of power provided since the battery provides additional power the grid power can be held more constant. A full article on implanting this process can be found here: https://www.csemag.com/articles/implementing-energy-storage-for-peak-load-shifting/. In addition, a graphical representation of the process is provided in Figure 2.

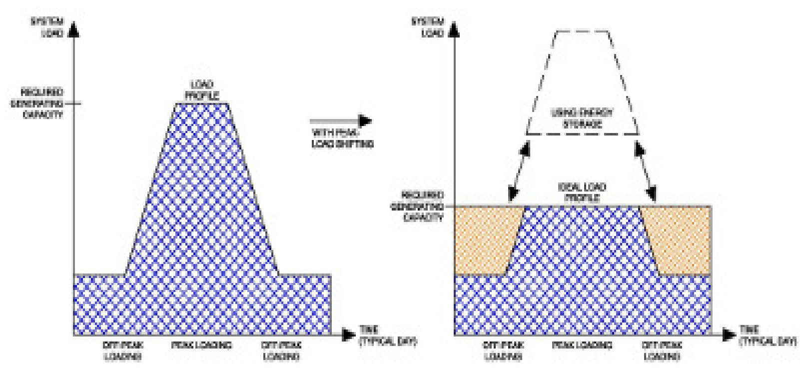


Figure 2. An Example of Peak Shaving

From the image, we see a typical load profile on the left. Here, the grid is taxed the most during peak hours. In the second image, the peak is removed as the supplemental energy storage system helps to provide power, and the extra power on nonpeak times is used to charge the supplemental energy storage system.

As seen with methods described above, the goal is to avoid significant spikes in power demand or minimizing high usage times. In both above-mentioned methods, a battery is used to supplement the power. Renewable energy, such as solar or wind energy, can also be used to supplement the power demand. Using these methods integrated with traditional methods can maximize the cost-effectiveness of the system. More information can be found here: https://www.nrel.gov/docs/fy15osti/63033.pdf.

3.3 Important Metrics

Some important metrics to know before continuing are cycle life, capacity, and rate performance (power). The cycle life refers to how long or how many cycles the storage system can provide until it fails or significantly degrades. Cycle temperature, depth of discharge (or SOC), and the C-rate will affect the cycle life. Calendar life is how long the battery energy storage system can be stored before it significantly degrades or fails – even if it is not used at all. Calendar life is impacted by voltage/state of charge and temperature. Capacity testing determines the amp-hour capacity of the battery between a set maximum and minimum voltage under at a predetermined discharge rate. The energy capacity, usually in kilowatt-hours (kWh), is the maximum amount of stored energy for a specified discharge rate over a set voltage range. Finally, the rated power is the total possible instantaneous charge/discharge capability of the energy storage system measured in watts. Typically, the battery capacity will fade over time, and the end of the battery life is generally accepted as 80% of the initial capacity—although secondary uses have been considered. Rate performance includes how much capacity the energy storage device can deliver under different rates of charge/discharge. Equally important is the SOC or the percentage of the battery's present level of charge. A SOC of zero is fully discharged battery and one is fully charged. It is also important to note that the temperature of the environment affects battery performance. Generally, cold weather impedes the performance of the battery and higher temperatures reduce its lifetime. For more information on metrics the two documents given in Section 3.2 also provide excellent definitions for additional terms.

3.4 Component/System Testing

When conducting tests, the tests can be done on cells, modules, or the entire system. The benefit of testing on cells is that it is easier, cheaper, and safer. The downside to this is that it does not represent the entire system, and a system is judged on its worst cell. Modules are a combination of cells, but not representative of the entire system. It gives some idea of how the cells will interact, while being cheaper than testing the entire system. Using modules is also a little safer because there is less risk of thermal runaway than in a system. The cons to using modules are that it still does not represent the entire system and is more expensive than cell testing. Finally, testing the entire system is beneficial because it gives the best picture of how the entire system will respond. Unfortunately, this process is more expensive, and usually the entire system must be installed to conduct these tests.

4 Performance Testing Protocols for Battery Energy Storage in Key Global Markets

One of the Energy Storage Partnership partners in this working group, the National Renewable Energy Laboratory, has moved forward to collect and analyze information about the existing energy storage test protocols and their use in different regions around the world. This chapter summarizes that information for several key regions globally. The goal of this chapter and this document broadly is to provide the reader with adequate background to reach out for additional information with an initial background in battery testing for performance.

4.1 United States Test Protocols

The United States has several sources for performance and testing protocols on stationary energy storage systems. This research focuses on the protocols established by National Labs (Sandia National Laboratories and PNNL being two key labs in this area) and the Institute of Electrical and Electronics Engineers (IEEE). Detailed information on the testing procedures outlined by Sandia and PNNL can be found in this document: "Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems."

From a Sandia report in collaboration with PNNL (Conover, et al 2016), extensive detail was given on peak shaving tests and frequency regulation tests for stationary batteries. For the protocol outlined here, all tests must be conducted on the entire system. All measurements, including (but not limited to): charge rate, input current and voltage, output current and voltage, thermal output, system temperatures, and ambient conditions, should be collected simultaneously at a temporal resolution applicable to the system. As an example, the peak shaving tests consist of the following:

- Capacity test (pg. 50)
- Round trip energy efficiency test (pg. 51)
- Response time test (pg. 54)
- Duty-cycle roundtrip efficiency.

The frequency regulation tests included the same tests as peak shaving while adding on a ramp rate test (pg. 53) and a reference signal tracking test. The page numbers listed next to the test correspond to example tests and test procedures for each type of test.

The IEEE has protocols similar to the steps outlined above and for other countries. Their protocols and test procedures must be purchased making them perhaps less viable for certain stakeholders or teams that are just getting started. An example of an IEEE protocol in this area is 1188. Protocol 1188 outlines testing procedures and test schedules for lead-acid batteries. Details for this standard can be purchased at this web address: https://standards.ieee.org/standard/1188-2005.html, and more standards can be found at that parent address. Some additional relevant standards that may be of initial interest are:

- 1679-2010: IEEE Recommended Practice for the Characterization and Evaluation of Emerging Energy Storage Technologies in Stationary Applications

- 2030.3-2016: IEEE Standard Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications

- 2030.2.1-2019: IEEE Guide for Design, Operation, and Maintenance of Battery Energy Storage Systems, both Stationary and Mobile, and Applications Integrated with Electric Power Systems

- P1526: IEEE Draft Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems

- 937-2019: IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems

- 1561-2019: IEEE Guide for Optimizing the Performance and Life of Lead-Acid Batteries in Remote Hybrid Power Systems

4.2 China

From our research on China, clear protocols for testing stationary energy storage systems were absent. However, our collaborators on the World Bank Energy Storage Partnership provided several key protocols that current support the energy storage industry in China. There are two significant standards currently in place:

- GB/T 36548-2018 (Test specification for electrochemical energy storage system connected to power grid)
- GB/T 36276-2018 (Lithium ion battery for electrical energy storage)

There are also regional standards and testing methods before grid connection, for example, China Southern Grid will conduct tests led by the Chinese Academy of Sciences before a system is connected.

There are also organizations which conduct battery tests, such as the China Quality Certification Center (中国质量认证中心) and China General Certification Center (鉴衡认证中心). Chinese Academy of Sciences also conducts lab tests.

4.3 The European Union Test Standards

Currently the European Union sets standards through the three officially recognized European Standardization Organizations: the European Committee for Standardization, the European Committee for Electrotechnical Standardization and the European Telecommunications Standards Institute. They create standards that are identified by 'EN'. They work closely with the European Commission to ensure that standards correspond with any relevant European Union legislation. The European Commission collaborates with the U.S. Department of Energy on standards.

Currently, almost all battery related EN standards are copies from the International Electrotechnical Commission (IEC) and International Standardisation Organisation (ISO) standards. A standardization mandate was given by the European Commission to develop EN standards to pillar their upcoming battery regulation.

There is currently a laboratory for battery testing in the Netherlands at the Joint Research Centre[2], part of the European Commission The procedures and tests conducted at this laboratory focus on material and cell testing. There is a plan to develop a pack performance testing facility, which will be able to assess batteries up to 100 kWh. The facility will also include safety testing for mechanical, electrical, and thermal abuse, and will include an X-ray tomography machine.

Current test procedures [5] conducted there include capacity and impedance testing, which relates to power. The capacity testing involves charging-discharging at a C/3 rate with a 20-minute relaxation between events. Another method uses a constant current 1C, constant voltage charging and constant current 5C discharging. A 20-minute relaxation period between charging and discharging is used here as well. In addition to these two methods, Telecordia, in partnership with the European Commission, has standard GR-3150-CORE. This standard outlines general requirements for lithium, nonaqueous batteries. The standard includes information on capacity testing and charge retention tests. More information on this standard can be purchased here: https://telecom-info.telcordia.com/site-cgi/ido/docs.cgi?ID=SEARCH&DOCUMENT=GR-3150&.

The European Association for Storage of Energy published an overview of the calculation of storage efficiencies: https://ease-storage.eu/wp-content/uploads/2016/03/Storage_efficiencies_EASE_Final.pdf.

In Germany, a measurement approach for PV-coupled home batteries has been developed:

- BVES Effizienzleitfaden für PV-Speichersysteme V1.0.4 (2017)
  - From 'Bundersverband Energiespeicher' in Germany. It provides test methods to determine the energy efficiency of home solar storage systems. It discerns the efficiency and energy losses of the inverter(s) and the battery separately.

In Germany, specific standard for coupling these systems to the electricity grid exists:

- E_VDE-AR-E_2510-2 Stationäre_Speicher_ans_NS-Netz
  About the safe connection of batteries to the low voltage grid
- E_VDE-AR-E_2510-50 Sicherheitsanförderungen Stationäre Li-ionspeicher
  Safety requirements for stationary battery energy storage systems with lithium batteries.

4.4 Indian Test Standards

The Bureau of Indian standards governs testing protocols for stationary energy storage systems for the country of India. As examples of standards, IS-1651 provides information on lead-acid cells and batteries using tubular positive plates and IS-1652 is for lead-acid cells and batteries with flat positive plates. Both standards provide comprehensive information on Ah capacities, dimensions, performance requirements, and test protocols.

IS-1651 includes descriptions for the following tests:

[2] https://ec.europa.eu/jrc/en/about/jrc-site/petten

- Capacity test
- Voltage test
- Amp hour (Ah) efficiency
- Watt hour (Wh) efficiency
- Loss of capacity on storage.

The capacity and voltage tests are run through the Institute of Testing and require that the temperature be kept between 25-35° Celsius. The IS-1651 protocol can be found at https://law.resource.org/pub/in/bis/S05/is.1651.1991.pdf.

IS-1652 includes many of the same testing procedures and specifications as IS-1651, but one of the key differences is the temperature requirement for tests. For IS-1652 the temperature needs to be within 38–160° Celsius. The protocol can be found at https://law.resource.org/pub/in/bis/S05/is.1652.1991.pdf

In summation, India has a robust national standard system for developing battery protocols. They also have an Institute of Testing to help them conduct some of the protocols. This report highlights two of the more relevant protocols, but more information can be found through the Bureau of Indian Standards.

4.5 Africa

The African Electrotechnical Standardization Commission is relatively new, as it was developed in 2008. Currently, all of their adopted standards are standards from IEC. They currently have published original works on smart metering systems in Africa and on the rural electrification of Africa. In both guides, they mention the IEC standards.

Along with Africa, the IEC has a strong presence throughout the world, especially in Europe after being founded in London. To highlight one of their relevant policies; IEC standard 60896-11 pertains to stationary lead-acid batteries giving general requirements and tests. Included in this standard are descriptions about capacity testing, a charge retention test, endurance in discharge-charge cycle, endurance in over charge, test for suitability for floating battery operation, short circuit, and internal resistance testing. For a complete list of policies adopted by the African Electrotechnical Standardization Commission, see this list https://ets.afsec-africa.org/index.html#/public.

4.6 United Kingdom

In England, many of the same standards previously mentioned have been adopted, such as those set by the European Commission and the IEC. In addition to those previously mentioned standards, there are also a set of British Standards. In particular, BS-6290 governs testing requirements for stationary lead-acid batteries. BS-6290-2 can be found here in full: https://shop.bsigroup.com/ProductDetail/?pid=000000000030018200. BS-6290-3 can be found here in full https://shop.bsigroup.com/ProductDetail?pid=000000000030018205. BS-6290-4 can be found here in full https://shop.bsigroup.com/ProductDetail/?pid=000000000030029878.

4.7 International Standards

IEC and ISO are developing standards for storage systems. ISO is focusing in this area on electric vehicles and environmental management. This is not the subject of this study. IEC, on the contrary, develops many standards specifically for stationary application of energy storages. Commercial product quality evaluation companies are also active in defining standards for storage systems and batteries, especially Underwriters Laboratory (UL). Since at least Europe as key global market is depending on their standards an overview is given here for stationary battery applications. More information on international battery standards is found in: http://ecodesignbatteries.eu/sites/ecodesignbatteries.eu/files/attachments/ED_Battery_Annex_Standards_V11_0.pdf. (See also section 2.1.1).

IEC TC120 Electric energy storage (EES) systems

This committee works on standardisation in the field of grid integrated EES Systems. It focusses on system aspects on EES Systems rather than energy storage devices.

IEC 62933-1 EES systems - Terminology

IEC 62933-2 EES systems - Unit parameters and testing methods of EES system - Part 1: General specification

IEC 62933-3 Planning and installation of electrical energy storage systems

IEC/TS 62933-4 EES Systems - Guidance on environmental issues

IEC/TS 62933-5 Safety considerations related to the integrated EES systems

Herewith some insight in the contents of the highly relevant IEC 62933-2 standard:

This standard is applicable on the following stationary applications: frequency regulation, fluctuation reduction, voltage regulation, peak shaving/peak shifting, back-up power. It prescribes performance tests for them.

It covers also test methods for the following unit parameters:

- Actual energy capacity
- Input and output power rating
- Round trip energy efficiency
- Expected service life
- System response
- Auxiliary power consumption
- Self-discharge of EES systems
- Voltage range
- Frequency range

IEC/TS 62933-4 provides guidance on environmental issues for stationary storage systems: It describes three aspects to identify environmental issues, namely life-cycle thinking, system aspects with respect to environment and storage technology independency. It also gives environmental guidelines on substance leakage, vibration, earth leakage current, weather conditions and life form invasion.

IEC TC21 Secondary cells and batteries

The scope of this committee is to provide standards for all secondary cells and batteries related to product, safety, testing, and safe application. For this study, the following standards are of interest:

- IEC 61427 series - Batteries for renewable energy storage

  They contain:

  - Part 1: Photovoltaic off-grid application
  - Part 2: On-grid applications

- IEC 62485 series - Safety requirements for secondary batteries and battery installations (with parts for Li-ion, lead-acid, and others)

  They contain:

  - Part 1: General safety information
  - Part 2: Stationary batteries
  - Part 3: Traction batteries (planned, no document)
  - Part 4: Valve-regulated lead-acid batteries for use in portable appliances (planned, no document)
  - Part 5: Safe operation of stationary lithium-ion batteries
  - Part 6: Safe operation of lithium-ion batteries in traction applications

- IEC/EN 60896 series - Stationary lead-acid batteries
- IEC 62932 series - Flow battery systems for stationary applications

  They contain:

  - Part 1: Terminology and general aspects
  - Part 2-1: Performance general requirements and test methods

    - Part 2-2: Safety requirements
- IEC 62984 series - High temperature batteries

  They contain:

    - Part 1: General aspects, definitions, and tests
    - Part 2: Safety requirements and tests of cells and batteries
    - Part 3: Sodium-based batteries – Performance requirements and tests

IEC SC21A Batteries with alkaline and other non-acid electrolytes

IEC SC21A prepares standards regarding product and test specifications for all secondary cells and batteries of sealed and vented designs containing alkaline or other non-acid electrolytes, being lithium batteries. Of interest are:

- IEC 62620 Secondary lithium cells and batteries for use in industrial applications
- IEC 62619 Safety requirements for secondary lithium cells and batteries for use in industrial applications
- IEC 63056 (under development) Safety requirements for secondary lithium cells and batteries for use in electrical energy storage systems.

Outside these technical committees another important battery storage related standard exists:

- IEC 60364-5-57 ED1 Low-voltage installations - Part 5 Selection and erection of equipment - Clause 57 Erection of stationary secondary batteries

Underwriter's Laboratory (UL)

Related standards to stationary storage systems are:

- UL 1642 UL standard for safety of lithium batteries
    - UL 1973 Batteries for use in stationary, vehicle auxiliary power and light electric rail applications (the scope of UL 1973 includes batteries for use as auxiliary power in recreational vehicles and for temporary energy storage system applications that are mobile but used as stationary energy storage.)

Other international standards of interest

- BATSO 02 Manual for evaluation of energy systems – Secondary Lithium Batteries (stationary applications)

4.8 Key International Organizations Available to Support Emerging Testing Laboratories

Energy storage testing centers within a country are an incredible resource as various energy storage technologies continue to evolve quickly. Accurate testing can increase the bankability of the technologies used in projects. While international testing standards are critical, national testing centers can provide local stakeholders with the confidence they need with experts that understand the local issues; however, the creation of a testing program and testing center can be daunting. Therefore, Working Group 3 has sought to create a list of key testing centers globally that can provide guidance, assistance, and documentation of testing protocols to these new testing facilities. The current list of key testing locations includes:

China:

Contemporary Amperex Technology Co, Limited (CATL)
General Contact Info:
No.2 Xingang Road, Zhangwan Town, Jiaocheng District, Ningde, Fugian, China, 352100
+86-(0)593-2583668

European Union

EnergyVille (Belgium)
EnergyVille develops technology and knowledge to support public and private stakeholders in the transition to an energy efficient, decarbonized, and sustainable urban environment. It has 15 laboratories.
Battery test laboratory
https://www.energyville.be/en/labs/battery-testing-lab

BESTEST - Battery Energy Storage Testing for Safe Electric Transport (JRC Petten)

https://ec.europa.eu/jrc/en/research-facility/battery-energy-storage-testing-safe-electric-transport

Fraunhofer
Fraunhofer Battery Alliance
www.batterien.fraunhofer.de

Ulm University
Dr.-Ing. Michael Buchholz
Room: 41.2.219
Phone: +49 (0)731 50 27003
michael.buchholz@uni-ulm.de

Warwick University
Energy Innovation Center
Dr Melanie Loveridge

Associate Professor Electrochemical Materials
M.Loveridge@warwick.ac.uk

Oxford University
Battery Test Lab
Dr. David Howey
david.howey@eng.ox.ac.uk

DER-lab: association of European laboratories on distributed energy sources
https://der-lab.net/

National Physical Laboratory (NPL)
Dr Juyeon Park
juyeon.park@npl.co.uk

United States

Argonne National Laboratory

https://www.anl.gov/pse/energy-storage

Idaho National Laboratory

https://at.inl.gov/SitePages/Energy%20Storage.aspx

National Renewable Energy Laboratory

https://www.nrel.gov/storage/index.html

PNNL

https://energystorage.pnnl.gov/

5 Test Data Database (From Cell to System)

The working group anticipates that the ongoing efforts of the Energy Storage Partnership will lead to the collection of publicly available component and system data. This may be in conjunction with the active energy storage testbed activities supported by the World Bank or it might be from other testing activities around the world. This section of the report seeks to make known that the World Bank has created a data repository for a wide variety of datasets but that this can include energy storage test data.

This data collection and sharing site is https://energydata.info/ and is managed and maintained by the World Bank. It has been established that public energy storage test data could be stored here.

We implore the other partners within the Energy Storage Partnership to contribute data sets of test data as available to this site. We feel that aggregation and sharing of test data for energy storage systems broadly—and quickly changing technologies specifically—will enhance understanding and reduce risk for future procurements. Both staff at the World Bank and members of this working group can coordinate collating and posting the test data if the provider is unable to do so.

Relatedly, the IEA has a working annex related to this activity. See IEA Technical Collaboration Program 'Energy Conservation and Energy Storage' annex 32: Modelling of Energy Storage for Simulation Optimization of Energy Systems: https://iea-eces.org/annex-32/.

6 Conclusions and Future Work

As stated at the outset, this document seeks to provide information to stakeholders in developing countries on the current global performance testing landscape of the battery systems. This document does that by summarizing testing protocols published by key global entities. From this summary, it can be concluded that there are several organizations within each region that set protocols for the testing and specifications of stationary energy storage systems. There are even some groups (such as the IEC) that aim at setting international standards. Across most of these entities, there are extensive protocols for testing batteries for electrical vehicles and mobile devices, but less for large scale energy storage system and their usage cases. Additionally, safety testing and performance testing are entirely different activities and we sought to focus on performance testing. In regions where there is an absence of extensive or relevant protocols for stationary energy storage systems, there may be the ability to adapt or expand on protocols for other energy storage systems that are available. Again, as stated at the outset, the working group and the Partnership more generally agree that the nascent markets for certain technologies and rapid growth make testing more important than ever as these markets continue to mature.

Additionally, this document seeks to provide a set of “guideposts” to new entrants by pointing out some of the key organizations globally that are currently engaged in performance testing of energy storage systems (often batteries but the larger organizations are likely to engage in tailored tests for emerging thermal and other storage technologies).

References

1. David R. Conover, Alasdair J. Crawford, Summer R. Ferreira, Jason Fuller, Sri Nikhil Gourisetti, David M. Rosewater, David A. Schoenwald, Vilayanur Viswanathan. *Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems*. Pacific Northwest National Labs and Sandia National Labs Report, 2016.

2. Kuriakose, Smita; Lewis, Joanna; Tamanini, Jeremy; Yusuf, Shahid. 2017. *Accelerating Innovation in China's Solar, Wind and Energy Storage Sectors*. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/28573. License: CC BY 3.0 IGO.

3. Pfrang, A., Di Persio, F., Kriston, A., Lebedeva, N., Ruiz, V., Dams, D., Kosmidou, T., Ungeheuer, J., Adanouj, I., and Boon-Brett, L. *Battery Testing Methods Assessed from a Policy-Making Perspective: Battery Materials and Cell Performance*. Presented at the EVS30 Symposium, Stuttgart, Germany, October 9-11, 2017. https://ec.europa.eu/jrc/sites/jrcsh/files/facility_evs30-5830703.pdf.

Recommended Resources

1. Poullikkas, Andreas. "A comparative overview of large-scale battery systems for electricity storage." *Renewable and Sustainable Energy Reviews* 27 (2013): 778-788. https://doi.org/10.1016/j.rser.2013.07.017.

2. Klausen, Mira. "Market Opportunities and Regulatory Framework Conditions for Stationary Battery Storage Systems in Germany." *Energy Procedia* 135 (2017): 272-282. https://doi.org/10.1016/j.egypro.2017.09.519.

3. Ericsson Information Superstore. GR-3150. "Generic Requirements for Secondary Non-Aqueous Lithium Batteries." Last modified January 2015. https://telecom-info.telcordia.com/site-cgi/ido/docs.cgi?ID=SEARCH&DOCUMENT=GR-3150&.

4. ITC India. "Battery Testing." https://itcindia.org/battery-testing/. May 2020.

5. IS-1652. Bureau of Indian Standards, 1991 (Reaffirmed 2002).