CHAPTER 21
ENERGY STORAGE SYSTEM COMMISSIONING

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Abstract

The commissioning process ensures that energy storage systems (ESSs) and subsystems have been properly designed, installed, and tested prior to safe operation. Commissioning is a gated series of steps in the project implementation process that demonstrates, measures, or records a spectrum of technical performance and system behaviors. This chapter provides an overview of the commissioning process as well as the logical placement of commissioning within the sequence of design and installation of an ESS.

Key Terms

Balance of plant (BOP), closeout, commissioning, energy storage system (ESS), factory witness test (FWT), functional acceptance test, installation, Operational Acceptance Test (OAT), procurement, request for proposal (RFP), shakedown, start-up.

1. Introduction

Commissioning is defined by the IEEE as "a process that assures that a component, subsystem, or system will meet the intent of the designer and the user."[[i]] It is a construction and systems engineering process designed to achieve, verify, and document that the performance of a device, system, or facility meets defined objectives and criteria in a safe manner. Commissioning offers sequential gated reviews that investigate responses to component and system level behavior, which is then documented in reports on the technical performance.

The general flow of the initial phases of an energy storage project implementation process (assuming a design build contract strategy) is shown in Figure 1. In design build, the winning bidder is responsible for the design, procurement, installation, and start-up of the system. In this chapter, the eventual operator of the system is assumed to be the owner. Commissioning is required by the owner to ensure proper operation for the system warranty to be valid. The activities relative to the overall design / build of an energy storage system (ESS) are described next. The details of the commissioning activities are described in Section 2.

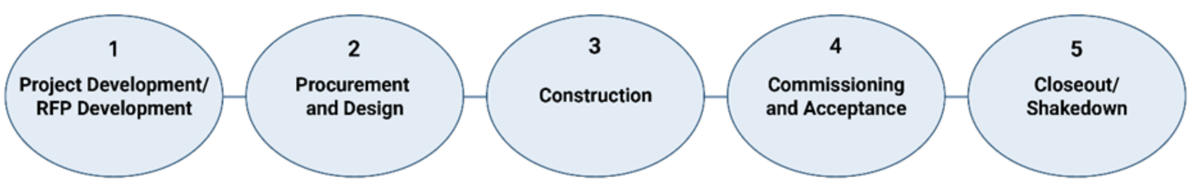

Figure 1. Overall flow of ESS initial project phases

1. **Project Development/RFP Development –** establishes the overall use case for the ESS, i.e., what problem(s) does the owner need the ESS need to solve and therefore what does the ESS need to do? Many use cases for an ESS are described in chapters 22: Energy

Storage Deployment and Lessons Learned and 23: Applications and Grid Services in this handbook. Once the need is established, and a commitment is made to initiate an ESS project, a Request for Proposal (RFP) is developed to distribute to the vendor community. This will include an overview of the problem(s) to be solved, system and safety requirements, codes and standards that need to be adhered to, and general specifications of the size of the system in energy and power units, as well as any other specific features and the general terms and conditions. The following commissioning requirements will be verified during the commissioning process: specifications, codes and standards, safety requirements, applications, and testing.

2. In the **Procurement and Design phase**, a vendor/contractor is chosen, i.e., a bid is accepted by the owner for construction and installation of the system. The proposal should include the overview of the contractor's commissioning program. The overview should outline the steps that will be taken during the commissioning process.

While not detailed, the commissioning overview should provide enough information for the owner to feel confident that the contractor understands all the relevant steps and can competently perform the commissioning process. Once the contract is awarded, a detailed system design should be submitted to the owner. The design should include all the relevant equipment specifications, shop drawings, and construction designs. Assuming the contractor is conducting the commissioning, the submittal should include the first draft of the commissioning plan discussed further below. If the commissioning will be conducted by a third party, all of the design submittals should be delivered to them so that they can start the process of developing the detailed commissioning plan. Typically, the commissioning team includes, depending on the size and complexity of the project:

- Owner
- Construction contractor
- ES equipment vendor (ideally a battery and its power conditioning system will be delivered together, even if they are manufactured by different vendors)
- ES system integrator
- Engineering designer (for ES installation and balance of plant)
- Inspectors
- Environment, Health, and Safety (EHS) representatives
- First responders
- Operations and Maintenance (O&M) personnel
- Utility representative (representing the point-of-connection of the ESS to the utility grid)

Construction project team members and project responsibilities are described briefly in Table 1. A more detailed look at commissioning team roles and responsibilities are in Table 2. This team reviews the design and any documents submitted that influence the commissioning plan. The commissioning plan is focused on testing activities, i.e. testing the sequence of operations (SOO) to demonstrate selected applications, performing balance-of-plant checkout, testing system controls, and exercising safety systems to the extent practical. During the design phase, the system must be designed so that all necessary tests can be performed with appropriate metering, data point identification and location, and access to the data. During this phase, the commissioning team develops the plan and confirms the change process. They also develop the ownership process – who owns what until when. (This is related to "Tags" discussed in Section 2.) Ideally, the commissioning plan will make use of checklists. Example checklists can be found in the EPRI Commissioning Guide [ii]. A traditional construction "punchlist" process is also established so that items not meeting specifications or needing repair will be addressed prior to project acceptance and handoff. During this phase, prior to construction, EHS requirements are established and a site incident prevention plan (SIPP) is developed.

Table 1. Construction project elements and team involvement

Team Member	Project Responsibility
Owner, Design Engineer	Programming
Design Engineer, Owner, Vendor, Installer, Authority having Jurisdiction (AHJ), Fire Staff	Design
Construction – Construction Contractor / Owner Commissioning – Owner	EHS / Safety Plans and Site Incident Prevention Plan (SIPP)
Site Construction Project Manager / Construction Staff	Safety Meetings
Vendor / Owner / Integrator	Factory Witness Testing
Installer / Owner	Site preparation / Construction
Design Engineer / Vendor / Installer / Owner / AHJ / Fire Staff / Commissioning Agent	Field Installation / Design verification
Owner / Vendor/System Integrator / Developer / Installer / Commissioning Agent	Pre-start inspection
System Integrator / Installer / Owner / Commissioning Agent	Operational Acceptance Testing (OAT)
System Integrator / Owner / Installer / Vendor / Commissioning Agent	Integrated System Startup (S/U)
System Integrator / Owner / Vendor / Commissioning Agent	Functional Acceptance Testing (FAT)
Owner / AHJ / Fire Staff / All / Commissioning Agent	Handoff / Training/Shakedown
Owner / All / Commissioning agent	Commissioning Closeout

Table 2. Commissioning Team Roles and Responsibilities

SUBJECT	Commissioning Manager (CM)	Owner's Work Group Lead	A&E Firm	Construction Management Firm	Core Commissioning Team/ Commissioning Agent	Owner QA/QC	Facilities Operations
Commissioning Procedures	Write/initiate & integrate sections written by others. Drive execution. Provides drafts of all sections.	Review & approve procedures by discipline. Support driving the commissioning process.	Support procedures writing and review as required.	Write & execute OATs. Drive the commissioning process.	Review procedures as required.	Write DV sections and checklists.	Writes/edits
Schedules	Prepare and maintain integrated commissioning schedule. Integrate into construction schedule. Provide schedule progress.	Facilitate integration of commissioning schedule into master schedule. Monitor and review schedule progress.	Provide equipment list for master schedule. Support CM maintenance of equipment lists.	Own and maintain construction schedule. Integrate communications schedule for critical components into construction.	Monitor and review schedule progress.	Communicate impacts to schedule.	Report Startup) (S/U), Functional Acceptance Test (FAT). Provide FAT durations to start-up schedule.
Factory Acceptance Test (FAT)		Witness test			Witness test	Witness test	Witness test
Design Verification (DV)	Integrate into commissioning process.	Define deliverable for DV checklists. Document changes via WP process.	Perform DV or verify design via SOR process. Write SOOs.	Integrate and track DV checklists.	Ensure DV is addressed in Commissioning Manual.	Write, execute or assist with DV as required.	Review DV checklists.
Site Incident Prevention Plan (SIPP)	Ensure SIPP program is followed.	Aware of SIPP process.	Aware of SIPP process.	Execute SIPP Program. Ensure SIPP training to contractors.	Audit SIPP process.	Aware of SIPP process.	Own SIPP. Provide SIPP training after Op-Ready.
Operation Acceptance Test (OAT)	Integrate OAT checklist in Commissioning Plan.	Review OAT checklist.		Write approved OAT checklist. Perform OATs.	Review OAT templates. Assist or perform verification and tests in OAT. Apply yellow tag	Review/witness and approve OATs as required.	Audit/Witness OAT's. Prewalk equipment & systems to verify S/U capability.
Equipment Startup (S/U)	Write S/U section of Commissioning Plan & schedule vendor support.	Review S/U Procedures. Identify critical spare parts & equipment training.	Perform Field DV or verify design prior to S/U.	Write/maintain S/U master schedule. Correct S/U issues. Facilitate O&M manual delivery to facilities.	Write Commissioning Procedures template. May assist or perform in equip. S/U.	Assist as required.	Edit/Approve S/U sequence. Perform or validate equip. S/U. Own monitoring, Operations & Training of Equipment.
Functional Acceptance Test (FAT)	Integrate FAT into Commissioning Plan	Review/support FAT execution.	Assist/review FAT as required.	Witness/support FAT as required.	Audit FAT procedure. Assist or perform FATs. Apply blue tag.	Assist as required.	Write and execute FAT. Apply *blue tag.*
Shakedown		Ensure Shakedown is in Master Schedule. Review/ participate in shakedown.		Provide Contractor Resources to support shakedown.	Provide historical Shakedown plans. Review procedures.	Assist as required.	Own. Write. Staff and execute the Shakedown Process.
Punchlist	Provide and maintain log and reports.	Attend training. Write Punchlist items. Own "in/out" of scope issues.	Attend training. Write Punchlist. Review Punchlist items for scope inclusion.	Attend training. Resolve Punchlist items.	Attend training. Write Punchlist items. Audit performance.	Attend training. Write Punchlist items & validate closure.	Attend training. Write Punchlist items & validate closure.
Vendor Support Program	Coordinate vendor support for commissioning.	Provide warranty. Equipment training. Co-approve equipment source inspections.	Resolve equipment/system performance design issues. Review O&M approach for compliance to specs.	Co-approve equipment via source inspection. Facilitate O&M, vendor training & warranty dates. Provide one set of O&M manuals to Facilities @ equip. delivery.			Validate vendor warranty in place. Fund/order critical spare parts. Participate if required in equipment source inspections.
Room Readiness (RR)	Own RR schedule and files checklists.	Review & participate in RR as needed.	Resolve design issues identified during RR.	Schedule and perform RR walk-through with Site Services.	Provide RR template.	Assist as required.	Site Services writes and performs RR checklist & accepts room.

3. **Construction** of the site infrastructure and balance-of-plant takes place during the construction phase as well as the installation and connection of the energy storage system. Figure 2 lists the elements of a battery energy storage system, all of which must be reviewed during commissioning, and are discussed in detail in Chapter 22 of this handbook. Each subsystem must pass a factory witness test (FWT) before shipping. (**Note:** The system owner reserves the right to be present for the factory witness test.) This is the first real step of the commissioning process—which occurs even before the energy storage subsystems (e.g., power conditioning equipment and battery) are delivered to the site. Ideally, the power electronic equipment, i.e., inverter, battery management system (BMS), site management system (SMS) and energy storage component (e.g., battery) will be factory tested together by the vendors.

Battery Storage	Battery Management System (BMS)	Power Control System (PCS)	Energy Management System (EMS)	Site Management System (SMS)	Balance of Plant
• Modules • Racks	• Battery management & BESS protection	• Bi-directional inverter • Inverter control • Interconnection/ Switchgear	• Charge/Discharge • Load management • Ramp rate control • Grid stability • Monitoring	• Distributed energy resources (DER) control • Synchronization • Islanding and microgrid control	• Transformer/POC switchgear • BESS container • Climate control • Fire protection • Construction and permitting

Figure 2. Elements of a battery energy storage system

Also, during this phase, the commissioning team finalizes the commissioning plan, documentation requirements, and design verification checklists. The commissioning plan includes start-up procedures based on an equipment list, system manuals, sequence of operations (SOO), and operating specifications (this includes parameters within which the system should operate). Test procedures can be based on established test manuals, such as the *Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems* [iii] or similar protocols.

4. Once the equipment arrives and is installed, the team conducts site observations and inspections and performs design verification (Does the system meet design specifications? Does it meet the codes and standards it must adhere to? Is it safe?). The team then performs basic equipment and system start-up and logs all discrepancies. The steps for these tests are found in the *Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems* [3].
5. The **Commissioning and Acceptance** phase is the heart of the commissioning process and is discussed in detail in Section 2.
6. Closeout/Shakedown activities correct any unresolved deficiencies. Closeout also includes updating commissioning documentation (e.g., in preparation for the ESS to be connected to the grid). Training of operators and first responders also occurs during or prior to closeout. Closeout and Shakedown are described in more detail in Section 2.

2. Current State -of-the-Art—On-site Commissioning

2.1. Implementation

Commissioning and acceptance include operational and functional test performance; assessment that installation and operation is per design and within tolerance; O&M training/documentation; review of applicable testing, adjusting, and balance requirements; and completion of a commissioning report. All safety features are also checked for functionality during this phase. The on-site commissioning steps are shown in Figure 3.

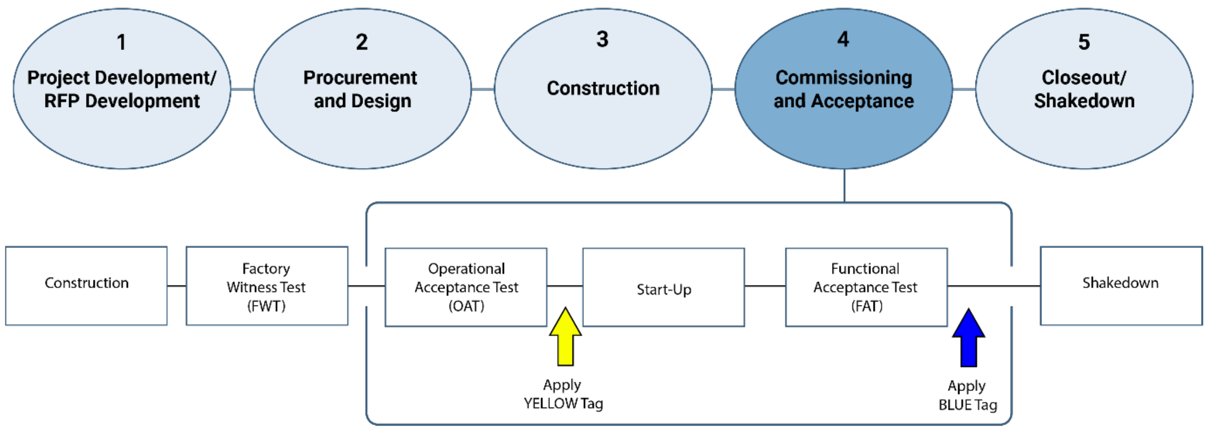

Figure 3. Commissioning process steps

2.1.1. Operational Acceptance Test

The first formal step of commissioning, Operational Acceptance Test (OAT), occurs once all the equipment has been installed on-site. The OAT determines that the individual components of the system operate as specified. During the OAT, the commissioning team will:

- Verify and test that the individual electrical, mechanical and safety components of the system are ready for start-up. During this step, some activities may include
    - testing the resistance of insulation,
    - testing the torque on bolts,
    - rotation/phasing of electrical circuits and machines,
    - checking the security of covers and barriers,
    - and smoke tests.
- Verify that the electrical controls are in place and test operation point-to-point
- Verify electrical protection and relays are coordinated and are operational
- Verify and test that all safety systems are installed and operating (to the extent possible without failure)
- Observe monitors of temperature, leak, security, fire alarm, flow, and pressure
- Verify and test that all communication systems are operating
- Ensure that emergency procedures are in place
- Ensure safety and operational signage is in place

A lockout/tagout process is implemented at the conclusion of the OAT. A yellow tag placed on equipment at this time means that it has been tested successfully and is ready to operate. The contractor is still responsible for this equipment because the handoff to the owner has not yet occurred.

The owner/operator (including members of the owners/operator the operations and /maintenance team) should be involved during the OAT phase to learn all system components and operations.

ABOUT TAGS
In a situation where a clear delineation of ownership between the contactor and owner is required, a tagging system is beneficial. In a tagging system, two distinct colors (or types) of tags are used. A (yellow) tag is placed on the equipment after it is commissioned and is operational but is still under the control of the contactor. Once the contractor has completed his or her work, and the system or piece of equipment is ready to be turned over to the owner, a (blue) tag is placed on the equipment showing that it is now under the control of the owner. The tags should be placed in a conspicuous location on the system or piece of equipment. A tagging system can help eliminate inadvertent operation of a system or piece of equipment that may be operational, but not necessarily complete (i.e., it could be missing safety or interlock components, or other systems that make it safe to operate may not be completed).

2.1.2. Start-up

Following the successful OAT, the commissioning moves into Start-up. While the individual components were verified and operated in the OAT phase, using start-up procedures established through the equipment vendor specifications and instructions, the commissioning team confirms that all the components operate **together** as a system. In addition to verifying operation, this is when the commissioning team should record the following baseline data:

- Voltages, currents
- Temperatures, flows, pressures
- Energy storage capacity (for batteries, this may require a means to measure state-of-charge)
- Charge time or rate of charge
- Discharge time or rate of discharge
- Firmware revision information
- Power electronic settings such as overcurrent, current limiting, and ramp rate settings

During this phase, if systems are operated for a period of time that allows for temperature fluctuations, the commissioning team should infrared (IR) scan the connections and energy storage components (batteries) to show unexpected or anomalous heat signatures, and record baseline.

The team also ensures:

- Automatic and remote controls are operating
- HVAC system, smoke exhaust, all safety notification signals (lights, sounds, or both) are functioning
- Annunciation (sounds or automated voices) and controls (emergency off, HVAC interlocks, and smoke exhaust) are working

- Data acquisition system is 1) operating, reading and recording data, and 2) displaying, saving, and transmitting data

During start-up, the commissioning team records errors or needed repairs as part of the ongoing punchlist process. Items on the punchlist must be corrected before the start-up phase is considered complete. The start-up phase can be time-consuming if significant repairs or modifications are needed.

2.1.3. Functional Acceptance Test

The Functional Acceptance Test (FAT) takes place at the completed installation connected to the utility grid. The integrated system is operated to demonstrate that the system properly performs its applications. This is accomplished by using testing procedures and pre-determined testing protocols, along with the manufacturer's testing plans and practices. Confirming that simulated grid signals are available and that successful system responses can be measured or observed are critical steps in preparing for the FAT.

The functions that are checked during the FAT include:

- All anticipated energy storage applications
- System control and annunciation during operation
- Remote operation and data gathering
- Cyber security features
- Baseline measurements, which should be logged (if not checked during the previous steps)

Other questions to be answered:

- Are all components and sub-systems operating in unison?
- Is the communication system sending and receiving data as intended, in terms of type and frequency? Are any anomalies being annunciated?
- Are the data collected adequate to determine system performance?
- Are all black start features operational? (See Chapter 23 for a definition of black start.)
- Does the system ramp appropriately to avoid overcurrent conditions?
- If multiple inverters are being used, is there a master and slave coordination to eliminate interference from one to the other?

Also, during the FAT phase, it is necessary to ascertain whether:

- Training for operators, maintenance, and first responders has been completed
- Day-to-day operation and maintenance plans are in place
- All emergency signage and response procedures are in place. For example, is a 1-800 number easily found in the event of an emergency? During an emergency the operators should not have to go and look for emergency response documentation. It should be readily available and visible for all from a distance.
- The warranty is documented and certified (Note: The warranty *must be* documented and certified)

After a successful FAT, the system is considered commissioned and handed off to the owner. At that time, the yellow tags should be replaced with blue tags to indicate that the owner/operator team can now operate the system.

2.1.4. Shakedown

Shakedown and closeout occur following the handoff and are the responsibility of the owner. The owner may perform the following shakedown testing activities to observe how the system operates under abnormal conditions, primarily a loss of power from the grid:

1. Connect the ESS to the grid as an operating system and repeat use case applications to assess possible optimization.
2. Disconnect the ESS from the grid to determine if systems work as designed or needed, systems fail in a fail-safe mode, back-up systems operate as expected, and alarms function properly.
3. Reconnect to the grid and determine if the systems come online in a safe manner and assess if backup systems turn off in a safe/ready mode.

2.1.5. Closeout Documentation

After the completion of the commissioning process, it is important to collect all the test results and baseline measurements into a singular closeout document. This information can be referenced during future maintenance activities to provide information about potential changes in the system or operation. For example, readings of the IR scan performed during commissioning can be compared to IR scans taken after a period of operation to check for temperature fluctuations in the system components. Also, initial capacity tests documented in the closeout documentation will allow the owner to determine if any capacity fade has occurred.

3. Challenges

Several challenges in an ESS commissioning process have been noted. All of these challenges can be minimized or avoided by careful planning.

1. **Design for Commissioning:** Sometimes commissioning is complex or difficult if access to measurement points or data screens is not considered in advance. System design that allows for the commissioning tests to be easily completed should be part of initial system design process.
2. **Scheduling:** Often one of the biggest challenges is timely scheduling of inspections and testing so that any needed corrections can be made and start-up can occur within the planned timeframe. In many cases, start-up is delayed because the right people have not been invited far enough in advance and/or insufficient time is built into the schedule for correcting any deficiencies.
3. **Safety Assessment:** As more energy storage systems have become operational, new safety features have been mandated through various codes and standards, professional organizations, and learned best practices. The design and commissioning teams need to stay current so that required safety assessments can be performed during commissioning. Safety assessments must include all appropriate documentation, indicating which safety-related functions were checked, since not all failure-related tests can be performed without

damage to the system. Recommendations from the research community and from the field regarding safety best practices should be included in the commissioning process.

4. **First Responders:** It is important that first responders play a role during commissioning. Their level of involvement should be dictated by the size and complexity of the system.

4. Concluding Remarks

Commissioning is a required process in the start-up of an energy storage system. This gives the owner assurance that the system performs as specified. A Commissioning Plan prepared and followed by the project team can enable a straightforward and timely process, ensuring safe and productive operation following handoff. As more energy storage systems are built by utilities and other users, the commissioning process should become more efficient.

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