Energy Storage and Microgrid Training and Certification (ESAMTAC)

**Course Syllabus**

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# Introduction

ESAMTAC (the Energy Storage and Microgrid Training and Certification) is a national, non-profit training and certification program based on standards and codes developed and/or approved by the National Fire Protection Association (NFPA), National Electrical Installation Standards (NEIS), National Electrical Code (NEC), American National Standards Institute (ANSI), and the Electric Power Research Institute (EPRI).

The ESAMTAC initiative was founded when energy storage industry stakeholders identified the need for a nationwide contractor network that possesses certified expertise in the safe and effective assembly, commissioning, maintenance and retrofitting of energy storage and microgrid (ESM) equipment and systems. Development of the program was supported by industry contributions and by the National Science Foundation.

The curriculum and lab activities are brand-agnostic and leverage the perspective of multiple subject matter experts in the design and construction of residential, commercial, and utility-scale ESM systems from the across manufacturing, construction, and energy sectors. The course develops knowledge and skills with an emphasis on energy storage and microgrid components, and includes a comprehensive examination. Successful graduates are awarded an ESAMTAC credential, and will be prepared to sit for an independently administered EPRI-approved Certification (forthcoming).

## Prerequisites for Training and Certification

Due to the specialty nature of ESM construction, and the variety of hazards and risk associated with this work, it is expected that participants in this program have significant prerequisite knowledge and the skill levels of a typical journeyman-level electrician. Prospective ESAMTAC students should (and, in the case of certification, must) meet or exceed at least one of the following minimum eligibility requirements:

1. Student is an electrician duly licensed or certified by the state or local authority having jurisdiction (AHJ) or, in states with no licensure/certification of electricians, has graduated a state or federally approved and accredited apprenticeship program,

or

1. Student is currently and actively enrolled in a state accredited electrician training program, or is an apprentice in a state or federally approved and accredited apprenticeship program, who has successfully completed a minimum of six (6) of the following prerequisite electrical training courses:
* DC electrical theory
* AC electrical theory
* Application and usage of electrical meters for measurement and verification
* Trouble-shooting feeders and motors
* Splicing and terminating conductors
* Control system installation
* PV solar installation and maintenance
* EVSE installation and maintenance
* Personal Protective Equipment (PPE) selection and proper usage
* OSHA 10 or OSHA 30
* Installation and maintenance of emergency or telecom battery systems

## Program Design and Vision

This course focuses on *component-level* understanding of ESM systems and the development of knowledge of ESM components and construction skills including how to safely and productively handle, assemble, and interconnect microgrid system components. Special emphasis placed on the construction of large stationary battery systems. ESAMTC Part 2 (currently in development)will focus on a *systems-level* understanding of ESM systems, emphasizing the processes and skills required to support the commissioning, operation, and maintenance of ESM systems, as well as the electrical skills and safety competencies necessary to supervise these activities.

**Exam /
Certification**

Prerequisite Knowledge / Experience

**ESAMTAC Part 1**

Energy Storage and Microgrid System Construction

**ESAMTAC Part 2**

ESM Commissioning, Operations and Maintenance

**Exam /
Certification**

Figure 1: Energy Storage and Microgrid Installation Certification Program Design Concept

# Curriculum Components

The ESAMTAC Curriculum is modular and consists of an introductory module and 11 Topical modules.

## Introduction Module

The Introduction Module is intended to present an overview of the ESAMTAC initiative including the rationale for its creation, how it was developed, how it is organized, and how it is expected to evolve in the future. The Introductory Module is intended to support a variety of teaching and training settings, and is designed to serve a variety of audiences. For example, in addition to serving as a launch for and ESAMTAC training course, the Introduction Module can be used as a short course or seminar presentation to stakeholder audiences including Electrical Contractors, Business Development professionals, and Manufacturers.

## ESAMTAC Modules

Module 1: Business drivers for energy storage and microgrid systems

Module 2: Distributed energy generation systems

Module 3: Energy storage systems and components

Module 4: Battery safety

Module 5: DC theory, grounding, and meters

Module 6: ESM control and communication systems

Module 7: ESM assembly methods and safety

Module 8: Battery enclosures, rack components and requirements

Module 9: Installation of batteries into racks and enclosures

Module 10: Connections between batteries

Module 11: DC devices, conductors, and connections

## ESAMTAC Instructor-led Laboratory Activities

Lab 4.1 – PPE selection for wet cell measurements

Lab 5.1 – Wet cell inspection

Lab 5.2 – Wet cell electrolyte testing

Lab 6.1 – Site analysis and MOP

Lab 6.2 – PPE selection for battery energy storage systems – Contactor replacement

Lab 9.1 – PPE selection for battery energy storage systems – String jumpers

Lab 9.2 – PPE selection for battery energy storage systems – PV voltage

Lab 10.1 – Making intercell and interbattery cables (jumpers)

Lab 10.2 – Making wet-cell intercell connections

Lab 10.3 – Connecting batteries and checking polarity

Lab 11.1 – Intertier and intercomponent cables

Lab 11.2 – MOP of multi-array battery system

Lab 11.3 – PPE selection for battery energy storage systems – Battery array voltage

# Course Modules

## Module 1: Business drivers for energy storage and microgrid systems

**Introduction and Purpose**

This module explains the defining features of microgrids and provides examples of common applications for microgrids. It also provides an overview of the factors that are affecting the growing microgrid market, and the regional nature of this market. Due to the significant contribution of energy storage systems (ESS) in the microgrid market, extensive descriptions of the services ESS can provide to the electric grid are also provided.

**Learning Objectives**

Part 1A: Introduction to Microgrids

* List defining characteristics of microgrid systems
* Describe the functions of microgrids and typical modes of operation

Part 1B: Microgrid applications

* Describe types of microgrid systems and common applications

Part 1C: Microgrid markets

* Understand value proposition of microgrid
* Understand expected trajectory of energy storage and microgrid systems
* Understand factors affecting their market development

Part 1D: Energy Storage

* Explain role of energy storage in microgrids and power distribution systems for different applications

**Key terms and acronyms**

ESS – Energy storage system: Typically, batteries, flywheels, capacitors with controls to dispatch use

T&D – Transmission and Distribution

TOU – Time of use

## Module 2: Distributed energy generation systems

**Introduction and Purpose**

This module focuses on the most common types of distributed energy generation systems that are used in microgrid systems. A focus is placed on the application of various types of generation sources and the interconnection requirements of major types of equipment. Topics include rooftop and ground mount solar photovoltaic arrays, inverters, and combined heat and power systems including reciprocating engines and gas turbines.

**Learning Objectives**

Part 2A: Solar Photovoltaic Systems

* Explain the hierarchy of the building blocks of PV systems and their role in building up DC voltage and current and factors impacting their efficiency and output
* Understand the grid-interaction and energy storage implications of the variability of solar resource

Part 2B: Inverters

* Explain the function and interconnection requirements of inverters and list their key specification variables

Part 2C: Combined Heat and Power (CHP)

* List key site requirements for feasibility of CHP and different approaches to extract heat and power
* Understand basic principles of operation for different CHP technologies and their key metrics

Part 2D: Other types of generation

* Describe other distributed generation technologies found in microgrids and their applications

**Key terms and acronyms**

PV-Photovoltaic

ramp rate control-controlling inverter ramp rate (% change in kW/min) to comply with grid requirements

Volt-VAR control (also called Volt-VAR optimization): optimally manages system-wide voltage levels and reactive power flow to achieve efficient distribution grid operation

Cogeneration (also abbreviated as “cogen”)-generating electricity and useful heat at the same time

CHP-Combined heat and power (same as cogeneration)- combination of an electrical generator and an engine mounted together to form a single piece of equipment that produces electrical power

ICE-Internal Combustion Engine

## Module 3: Energy storage systems and components

**Introduction and Purpose**

This module examines the primary types of energy storage systems encountered in microgrid systems with an emphasis on battery technologies. The internal components, charge and discharge properties, and unique properties of lead acid and lithium ion (LI-Ion) are emphasized. A high level overview of types and applications for less common energy storage technologies is also included (flow battery, capacitors, compressed air, and ice storage).

**Learning Objectives**

Part 3A: Properties of batteries

* Recall and order different units of battery organization from cell to system and list most common voltages
* List the three main components of an electrochemical cell and explain their function during charge and discharge
* Explain key battery specification and condition variables and their interrelationship
* List key battery system variables and explain how they are related to cell-level variables

Part 3B: Lead-acid battery characteristics

* Identify material used for three main cell components in Lead Acid batteries and how they contribute to safety handling of batteries; relate their physical characteristics to battery specification variables (i.e. thicker plates and larger acid volume to higher capacity and longer discharge duration)
* Explain unique charge and discharge characteristics of Lead Acid batteries, list three stages of Lead-Acid charging (bulk, absorption and float charging) and explain how they vary with rate of discharge (C-rate) and temperature
* Understand PeuKert’s law for Lead-Acid batteries (as charge rate increases, available capacity decreases)
* Explain procedures for the disposal and recycling of Lead Acid batteries
* Recall specification variables for a sample Lead-Acid battery
* List different types of Lead-Acid batteries (VLA[vented] and VRLA[valve-regulated:gel and AGM as well as ultra-batteries] and their applications

Part 3C: Lithium battery characteristics

* Identify material used for three main cell components in Li-Ion batteries how they relate to safe handling of batteries; list different form factors of a Li-ion cell (cylindrical, prismatic, and pouch) and their applications (home energy/EV, home energy/portable electronics, portable electronics)
* Explain the concept of thermal runaway of Li-ion batteries
* Explain unique charge and discharge characteristics of Li-Ion batteries and how they vary with rate of discharge (C-rate) and temperature; list different charging stages of a Li-ion battery
* Explain procedures for the disposal and recycling Li-ion of batteries
* Recall specification variables for a sample Li-ion battery
* List different Li-ion chemistries and their applications
* Recognize key application-specific advantages of Li-ion batteries: higher energy density and depth of discharge

Part 3D: Other types of energy storage systems

* List other types of energy storage technologies including flow batteries, capacitors, compressed air, and ice storage, thermal storage . . NECA 416

**Key terms and acronyms**

DOD-Depth of discharge

SOC-State of charge

SOH-State of health: reflects the general condition of a battery (expressed in %) and its ability to deliver the specified performance compared with a fresh battery (100%)

C-rate-Charge Rate: Measure of the rate at which a battery is being discharged. Expressed in “C/n” as rated current for an n hour discharge rate

Coup de fouet-French for “stroke of the whip”: Initial voltage drop and recovery experienced when discharging a lead-acid battery.

AGM-Absorbed Glass Mat

VLA-vented lead acid (same as “flooded” or “wet cell”)

VRLA-valve-regulated lead-acid cell: A lead-acid cell that is sealed with the exception of a valve that opens to the atmosphere when the internal pressure in the cell exceeds atmospheric pressure by a preselected amount. VRLA cells provide a means for recombination of internally generated oxygen and the suppression of hydrogen gas evolution to limit water consumption

Li-ion-Lithium-ion

LiPo-Lithium-ion polymer

## Module 4: Battery Safety

**Introduction and Purpose**

This module focuses on the unique safety issues associated with ESM system construction. An emphasis is placed on Lead Acid and Li-Ion battery systems and the unique hazards associated with these chemistries. Applicable codes governing safety are presented. Types and use of personal protective equipment (PPE) are discussed. The design and use of emergency action plans are discussed as an instrument to synthesize hazard analysis and safety planning.

**Learning Objectives**

Part 4A: Battery safety and lead-acid battery hazards

* Recall relevant codes and standards that apply to ESM safety
* Identify unique failure modes hazards of lead-acid batteries related to overcharge and over discharge
* Recognize fire risks associated with applicable chemistries

Part 4B: Lithium ion battery hazards

* Identify existing and predictable hazards associated with specific battery chemistries
* Identify unique failure modes hazards of Li-Ion batteries related to overcharge and over discharge
* Recognize fire risks associated with applicable chemistries
* Perform risk assessment with respect to battery hazards

Part 4C: Job hazard analysis

* Identify appropriate PPE for chemical hazards
* Identify PPE based on shock and arc fault risk assessment

Part 4D: Emergency action plans for battery systems

* Describe use of spill kits for lead-acid batteries
* Create emergency action plans
* Describe how work plan / method of procedure affects arc fault and shock risk assessment

**Key terms and acronyms**

PPE-Personal protective equipment

Sulfation (lead-acid)- build-up of lead sulfate crystal, occurs when a lead acid battery is insufficiently charged during normal operation. If continued, sulfate deposits can ultimately expand, crack the plates, and destroy the battery

Electrolyte spill- Electrolyte (acid) dripping out of the battery case, usually as a result of accidents during moving and handling of batteries but also during any of the following: old age, overcharging, earthquake/natural disaster, and battery fires

Neutralizing agent- A base that as a result of its chemical with electrolyte (acid) spilled out of the battery results in neutralizing its caustic and corrosive effects and removal of hydroxide ions present in the solution

Plating (Li-ion)- The formation of metallic lithium on the negative graphite electrode in a lithium-ion battery

Thermal runaway (Li-ion) - rapid uncontrolled increase in temperature triggered by internal short circuits, physical damage, or overheating of the cell (typically from exposure to temperatures above 60°C). The result of thermal runaway in a lithium-ion cell is typically a fire or explosion.

Dendrite (Li-ion)- lithium metal structures growing outward from the anode (negative terminal during) due to repeated charging and discharging cycles of the lithium battery. If they grow towards the cathode and pass through the separator and electrolyte layer and reach it, the resulting electrical short circuit and can further impose a safety risk (fire) due to overheating of the battery.

SDS-Safety Data Sheet

**Lab Activity (s)**

Lab 4.1 PPE selection for wet cell measurements

**Evaluation**

Written Exam

Skill test: Lab 4.1, 4.2: Identifying appropriate PPE and develop emergency action plan for acid spill and thermal runaway

## Module 5: DC theory, grounding, and meters

**Introduction and Purpose**

This module focuses on DC power systems including a review of Ohm's law and calculations of voltage and amperage in DC circuits. It discusses the common grounding configurations typically found in dc systems as well as pertinent code sections, how grounding affects electrical hazards, and the implications and causes of unintentional grounds. The selection and use of DC meters and battery testing are also included and reinforced in laboratory activities.

**Learning Objectives**

Part 5A: Voltage and current in series and parallel DC systems

* Recall accumulation of voltage and current in series and parallel connections respectively (similar to PV)

Part 5B: Grounding in dc systems

* Recognize the differences between dc system grounding
* Recognize the electrical hazard implications of grounding in dc systems
* Explain difference from grounded, ungrounded, and grounding
* Recognize requirements for grounded and ungrounded systems and ground fault detection systems

Part 5C: DC meters and battery testing

* Select appropriate meter and properly measure voltage in accordance with code

Part 5D: Wet cell battery testing and care

* Perform battery variable measurements and interpret results including hydrometer and digital multi-meter

**Key terms and acronyms**

Battery/system *charge* capacity (same as Battery/system capacity)- The amount of charge that can be stored in a battery; expressed by the number of hours for which a battery/system can provide a current equal to the discharge rate at its nominal voltage, has the unit of Ampere Hours (Ah).

Battery/system *energy* capacity- The amount of energy that can be stored in a battery. Obtained by multiplying nominal voltage and charge capacity, has the unit of Watt Hours (Wh).

Battery cell- smallest unit of electrochemical storage consisted of positive terminal (cathode when discharging), negative terminal (anode when discharging), and electrolyte

Battery module- Aggregation of several cells either in series or in parallel. Modules consisted of few cells in series where the cells are not externally accessible are often simply called batteries as opposed to modules (i.e. a 12 V Lead Acid battery consisted of 6 2V cells in series, all enclosed in one battery case

Battery pack- Aggregation of several modules in series and/or parallel

Battery system- Aggregation of several packs

Most positive/ most negative end of array-

Ungrounded dc system- Neither pole of the battery is connected to ground

Grounded dc system- There is a

Solidly grounded dc system- A grounded dc system where either the most positive or most negative pole of the battery is connected directly to ground

Negative grounded dc system- Solidly grounded dc system

Positive grounded dc system- Solidly grounded dc system

Resistance grounded dc system- A grounded dc system in which either the battery is connected to ground through a resistance

Grounding electrode conductor- A conductive body extended to the ground connection

Equipment grounding- Grounding of electrical equipment involves connecting equipment to the ground (Earth), either directly or through a conductive body that extends the connection to the ground

DC Ground fault detection system- (mandatory for ungrounded DC systems)

**Lab Activity (s)**

Lab 5.1 Wet Cell Inspection: Perform basic inspection of a wet cell battery prior to installation of inter-cell connectors and/or terminal plates and ay additional testing.

Lab 5.2 Wet Cell Electrolyte Testing: Includes determining the appropriate level of electrolyte in a wet cell.

## Module 6: ESM control and communication systems

**Introduction and Purpose**

This module focuses on the types of controls and communications conductors and connections found in ESM Systems. Topics include types of monitoring, controls, and communication systems found in ESM systems with an emphasis placed on the functions of battery management systems (BMS). Types of conductors and connections are also discussed as well as the planning of installation of these systems with respect to the balance of assembly activities. Due to the significant variability in these systems, and emphasis is placed upon interpretation of manufacturer specifications.

**Learning Objectives**

Part 6A: Types of monitoring, control, and communication systems

* Describe how the architecture of BMS impact control wiring and termination

Part 6B: Functions of Battery Management Systems

* Describe the main functions of a Battery Management System (BMS)
* Recognize the significance of cell charge balancing and recall the role of BMS in balancing
* Recognize the significance of key variables monitored by the BMS and communicated to the site controller and their safety implication

Part 6C: Types of conductors and insulation/shielding

* Describe termination methods and connections for BMS systems
* Identify correct wire type for control wiring
* Describe the impact of electrical interference on control wiring (shielding, twisting, etc)
* Interpret manufacturer’s wire specification

Part 6D: Planning installation of communications and controls

* Describe where in the installation MOP control wiring should occur in order to limit arc flash and shock hazards during the installation of BMS components and wiring

**Key terms and acronyms**

BMS (Battery Management System)-Manages ESS State of Charge; monitors commands the site controller if operational, environmental; consisted of BMS controller, BMS communication and control wirings and cell board electronics connected to individual cells or modules

HMI- Human-Machine Interface

Site Controller- Remotely accessible on-site computer (including specialized software) tasked with managing ESS charging and discharging and energy interactions with the grid by commanding the BMS and the inverter control system and interacting with local curtailment service provider or utility and displaying them through its HMI

Fully centralized BMS- A BMS where the BMS controller is wired to and communicates directly with all cell boards

Fully distributed BMS- A BMS where cell boards are connected in a single daisy chain (similar to lights in a Christmas tree) which also includes the BMS controller (connected to the first and last cell board)

Cell balancing- The act of balancing State of Charge (SoC) in a string of cells connected in series by attempting to equalize the SoC between different cells to the extent possible

Dissipative (passive) cell balancing- Removing charge (and energy) from the most charged cell (dissipating it on a bleed resistor), implemented by the BMS controller and cell board electronics

Nondissipative (active) cell balancing- Transferring energy (and charge) from the more charged cells to the less charged cells, implemented by the BMS controller, specialized circuitry, and cell board electronics

CAN bus (Controller Area Network)-A communication protocol, designed originally for multiplex electrical wiring within automobiles (Originally Bosch), but is also used in many other contexts including BMS (communications between BMS controller and cell boards)

Modbus- A serial communications protocol originally published by Modicon (now Schneider Electric) in 1979 for use with its programmable logic controllers (PLCs); a de facto standard communication protocol for connecting industrial electronic devices including between the site controller and inverters

**Lab Activity (s)**

Lab 6.1 – Site Analysis and Method of Procedure (MOP)

Lab 6.2 – PPE Selection for battery energy storage systems – Contactor replacement

## Module 7: ESM assembly methods and safety

**Introduction and Purpose**

This module provides an overview of the hierarchy of codes and standards that apply to ESM systems. Subjects covered include the hierarchy of Codes and Standards, Rules for product certification, and safety, adoption and application of codes and standards, and workmanship. An emphasis is placed on the distillation of key codes and standard in the creation of a method of procedure (MOP) for ESM system construction.

**Learning Objectives**

Part 7A: Organization and review of codes and standards

* Recall relevant codes and standards and applications in energy storage and microgrid construction
* Describe Arc Flash and Arc Fault

Part 7B: Method of procedure design

* Describe the assembly process and methods of procedures for building energy storage systems
* Read and interpret blueprints, shop drawings, vendor diagrams of ESM equipment
* Demonstrate role of planning to minimize risks and related PPE

Part 7C: Work involving electrical hazards

* Demonstrate justification of thresholds for energized work
* Demonstrate familiarity with electrical shock hazards

Part 7D: Arc and shock risk assessment and PPE selection

* Describe arc flash and arc fault
* Select appropriate PPE

**Key terms and acronyms**

JHA- Job Hazard Analysis

JSA- Job Shock Analysis

RAB- Restricted Approach Boundary

LAB- Limited Approach Boundary

AFB- Arc Flash Boundary

AFRA- Arc Flash Risk Assessment

ASCC- Available short-circuit current

Prospective Short-Circuit Current: Highest electric current which can exist in a particular electrical system under short-circuit conditions

## Module 8: Battery enclosures, rack components and requirements

**Introduction and Purpose**

Battery enclosures and racks serve as the physical platform on which batteries will be located. This module presents the key types and features of battery racks and enclosures. The need for specialty types of spill mitigation, ventilation, and fire protection for various types of chemistries is included. A review of rigging and hoisting procedures is also included due to the high density and risks associate with setting of large prefabricated battery enclosures.

**Learning Objectives**

Part 8A: Types of Racking Systems for Batteries

* Interpret manufacturer’s installation guidelines and manuals and impacts on applications, access requirements and placement
* Identify relationship of rack to chemical, fire, and seismic hazards and requirements
* Explain how the rack relates to the MOP of the installation of batteries, conductors, grounding/bonding and other installation requirements

Part 8B: Battery Enclosures

* Recognize arc flash hazards are significantly increased where batteries are installed inside an enclosure (arc in a box)

Part 8C: Spill Mitigation and Ventilation

* Plan ahead for necessary racking considerations such as spill mitigation
* Describe active and passive ventilation systems and requirements for batteries

Part 8D: Rigging, Hoisting, and Anchoring of prefabricated battery enclosures

* Knowledge of rigging and hoisting practices
* Demonstrate ability to us lift tables

**Key terms and acronyms**

Battery stacking- Arranging batteries in a grid configuration and interconnection of their terminals to generate a specific series and parallel connectivity between them based on specified current and voltage requirements of the system

Seismic racking- Racking classifications based on earthquake zones in the U.S. (Zones 0-4; i.e. Zone 2 racking), officially denoted as “seismically certified.”

Multi-tier/step/row racking- A racking system consisted of several tiers/steps/rows as depicted in the training material and based on seismic requirements of installation site

Intertier Conductor- Conductor connecting one group of batteries to another, typically when transitioning tiers

Intercell Conductor- Conductor connecting one battery to another

pH: Potential of Hydrogen- a quantitative (0-14) measure of the acidity or alkalinity of a solution. Lower numbers correspond with a stronger acid and larger numbers correspond to a stronger base. A neutralizer should be able to safely convert the electrolyte to a pH between 5.0 and 9.0.

Electrolyte Specific Gravity- Ratio of the mass of the electrolyte to the mass of water for the same given volume, for example a specific gravity of 1.2 for the electrolyte in a wet cell battery).

## Module 9: Installation of batteries into racks and enclosures

**Introduction and Purpose**

Modern energy storage and microgrid systems utilize battery systems that require racking and stacking of batteries on site. Also, a need may arise for a single battery to be replaced in a system. This module focuses on the planning and execution of battery installation into racking from initial acceptance testing of batteries to loading of batteries in racks and enclosures in preparation for interconnection. An emphasis is placed on the proper PPE, lifting procedures, and short-circuit/shock protection of this operation. As many ESM project include scheduled replacement of batteries, the topic of battery disposal and recycling is also addressed.

**Learning Objectives**

Part 9A: Planning Battery Installation Process

* Understand and apply workspace requirements to battery installation
* Recall different insulation techniques for individual battery stacks to avoid short circuits and damage to the battery
* Select appropriate PPE for chemical, arc, and shock hazards
* Identify the staging placement, temperature and path requirements for battery staging
* Describe the relationship of batteries to the racking construction MOP

Part 9B: Acceptance Testing of Batteries

* Describe acceptance testing procedures for batteries
* Follow emergency and first aid procedures listed in SDS
* Describe safe handling and storage procedures of broken batteries

Part 9C: Lifting and Moving Batteries

* Describe how to safely lift and transport batteries from a staging area to their final location on a rack
* Organize batteries into optimal orientation for series and parallel connections

Part 9D: Battery Disposal and Recycling

* Explain the use, storage, maintenance and disposal of used batteries

**Key terms and acronyms**

MOP-Method of Procedure

Internal Ohmic Measurement-Internal resistance calculated by applying Ohm’s law and taking into account terminal reading s for open circuit and under-load conditions

Top-off charge- Charge required to compensate for battery self-discharge when storing batteries (not applicable to Li-ion unless storing for very long periods)

Discharge rate- The temperature-dependent rate (% per month) at which loss of charge occurs during battery storage

**Lab Activity (s)**

Lab 9.1 – PPE selection for battery energy storage systems – String jumpers

Lab 9.2 – PPE selection for battery energy storage systems – PV voltage

## Module 10: Connections between batteries

**Introduction and Purpose**

Battery energy storage systems are comprised of strings of batteries stacked in a specific way in racks or enclosures. This module focuses on the interconnection of individual batteries units into stings, and the specialty hardware and measures required for proper connections. The accumulation of voltage and hazards in workspaces as batteries are connected is emphasized. Workmanship issues are also addressed, including the preparation of terminals, use of anti-oxidation compounds, and proper torqueing procedures.

**Learning Objectives**

Part 10A: Planning parallel and series string connection process

* Interpret stacking and terminal diagrams
* Explain the accumulation of shock and arc flash hazards as series and parallel connections buildup voltage and current
* Describe how PPE requirements change as hazards accumulate due to battery connections
* Understand requirements to provide the ability to disconnect series connected strings to limit voltage per NEC 706.30(B)
* Describe how the integration of balancing circuits and monitoring systems may affect MOP

Part 10B: Types of connection methods and hardware

* Identify unique connection hardware specified by manufacturers
* Identify components required to terminate finely stranded cable

Part 10C: Preparation of terminals and lugs

* Explain when anti-oxidation compounds are and are not necessary/required
* Explain when insulated tools are necessary

Part 10D: Torqueing of connections

* Apply appropriate torque to connection hardware
* How connections need to be monitored over time
* Perform solid electrical connections in compliance with NEC 110.14

**Key terms and acronyms**

Connection diagram- A diagram depicting series and parallel connections in the energy storage system

Battery polarity- Specifying positive and negative terminals. During discharge (charge), current flows out of (into) the positive terminal and into (out of) the negative terminal

Battery orientation-Relative physical position of batteries in a system with respect to each other. Some batteries can be installed in more than one orientation which has implications on the position and interconnection of their terminals

Galvanic corrosion (also called dissimilar metal corrosion)- A chemical reaction that results in corrosion damage that takes place when two dissimilar materials (for example battery terminal and the connector cable) are coupled directly and a corrosive electrolyte is present

Corrosion inhibitor- A chemical that once it is deposited on the battery terminal, creates a protective film around the terminal that hinders corrosion

NO-OX-ID- An anti-oxidation compound (a conductive grease substance) used on electrical connections where copper and/or aluminum join to prevent corrosion and keep connection resistance low

**Lab Activity (s)**

Lab 10.1 – Making Intercell and Interbattery Cables (Jumpers): Select the tools, PPE and supplies needed to construct a cable with connectors according to given specifications

Lab 10.2 – Making Wet-Cell Intercell Connections: Select the components, tools, PPE and supplies needed to connect the cells of the 3CC-3M battery in series to create a single 6Vnom battery and perform the connection.

Lab 10.3 – Connecting batteries (cells), checking polarities and voltages: Develop a wiring plan; connect batteries within a row

## Module 11: DC devices, conductors, and connections

**Introduction and Purpose**

This module addresses the interconnection of energy storage and microgrid components using DC cabling. Unique features of DC cable are addressed including types of DC cable and the calculation of voltage drop. Types and locations of over-current protection devices and disconnects are discussed. The planning of DC connections and the relationship of this process to the accumulation of hazards is discussed including the relationship of this sequence to order of operations and method of procedure. The workmanship issues associated with DC cabling and terminations are also discussed, with an emphasis on fine twisted strand cable typically used in ESM systems.

**Learning Objectives**

Part 11A: Over-Current Protection in ESS Systems

* Describe the types of OCPDs in ESS systems
* Describe the differences between AC and DC overcurrent protection

Part 11B: Calculating voltage drop in DC cables

* Explain the relationships between other DC energy systems incorporated in system
* Describe the effects of voltage drop on DC cable runs
* Explain why such large conductors are used in ESS

Part 11C: Planning of DC connections between ESM system components

* Verify the correct conductor sizes types and review OCPD
* Describe the accumulation of hazards throughout the power connection process
* Describe how the accumulation of hazards affects the order of operations and MOP

Part 11D: DC cabling and termination workmanship

* Understand cable insulation properties
* Describe the different types of wiring methods (conduits and cable support)

**Key terms and acronyms**

Direct Current rating- Appropriate voltage, current, and interrupting ratings for overcurrent protective devices under DC loads

Thermal protection (circuit breaker)-protecting the circuit against overload current (slightly larger than normal operating current)

Magnetic protection (circuit breaker)-Instantaneously protecting the circuit against shorts and high fault currents (drastically larger than overload)

RMS-Root Mean Squared; The amount of AC power that produces the same heating effect as an equivalent DC power

Zero crossing- The moment (repeated every half cycle or 1/120 of a second in the U.S.) AC voltage changes polarity; Important implication in larger sizing of DC overcurrent protection vs AC as the former never has this opportunity

MPPT (Maximum Power Point Tracking) window- The voltage window that an inverter operated within so that maximum DC power is generated; if voltage drops on DC conductors are excessive, the inverter will fail to operate in this window

Load break disconnect switch- A switch (especially applicable to microgrid islanding) that has been designed to provide making or breaking of a specified current (while the circuit is under load); accomplished by addition of equipment (stored energy/motor operated) that increases the operating speed of the disconnect switch blade

IACS- International Annealed Copper Standard; empirically derived standard value for the electrical conductivity of commercially available copper by the United States Department of Commerce (circa 1914)

LVD (Low Voltage Disconnect)- A mechanism in the inverter input circuit that will automatically turn off the inverter connected to the battery if the battery voltage falls too low (i.e. below 12V, 24V, or 48V) ( if this doesn’t take place, apart from battery damage, the inverter input circuit current can raise beyond its acceptable threshold

Charge and discharge voltage set point- The temperature and charge/discharge current dependent voltage for the corresponding higher and lower state of charge limits specified for the battery

**Lab Activity (s)**

Lab 11.1 – Intertier & intercomponent cables: construct intertier cables with connectors according to given specifications

Lab 11.2 – Method of Procedure for Multi-array ESS Installation: Develop a method of procedure for the wiring of a multi-string, high-voltage battery system

Lab 11.3 – PPE selection for battery energy storage systems – Battery array voltage

# Lab Activities

## LAB 4.1: PPE Selection for Wet Cell Measurements

**INTRODUCTION**: Working with vented lead-acid (VLA) batteries, also known as wet cell or flooded batteries, exposes workers to chemical hazards in addition to the electrical hazards commonly encountered. Determining and donning the appropriate PPE for these situations and working safely can become challenging due to the multitude of hazards that are encountered and for which the PPE must be rated.

The purpose of this lab is to interpret the provided work order, identify the tasks required to complete the prescribed work, perform the necessary risk and hazard analyses, utilize the hierarchy of risk control methods, and select and don the appropriate PPE for the prescribed tasks.

**OBJECTIVE:** To be able to identify the risks and hazards associated with a provided work order, apply the hierarchy of risk control methods and conduct the applicable risk assessments to select the appropriate PPE required after all control methods are exhausted.

## LAB 5.1: Wet Cell Inspection

**INTRODUCTION**: Vented lead-acid batteries~~,~~ are often referred to as flooded or wet cell. Such batteries require both constant and scheduled maintenance and inspection in order to assure consistent performance as well as battery health. Inspections are performed during material acceptance, prior to installation steps, and during scheduled maintenance routines. Each type of inspection and/or testing has a different level of sub-tasks performed to support the intended task.

**OBJECTIVE:** The purpose of this exercise is to conduct a basic inspection of a wet cell battery. Acceptance inspections would have been performed when the wet cell was received and installed in the battery racking system. For the purpose~~s~~ of this lab exercise a basic inspection shall be performed. This procedure should always be performed prior to the installation of intercell connectors and/or terminal plates and any additional testing.

## LAB 5.2: Wet Cell Electrolyte Testing

**INTRODUCTION**: Vented lead-acid batteries are often referred to as flooded or wet cell. Such batteries require both constant and scheduled maintenance and inspection in order to assure consistent performance as well as battery health. Inspections are performed during material acceptance, prior to installation steps, and during scheduled maintenance routines. Each type of inspection and/or testing has a different level of sub-tasks performed to support the intended task.

**OBJECTIVE:** The purpose of this exercise is to conduct an inspection of the electrolyte level in a wet cell battery. This inspection will include determining the appropriate level of electrolyte, measuring the specific gravity of the electrolyte and applyingany applicable correction factors.

## LAB 6.1: Site Analysis and Method of Procedure (MOP)

**INTRODUCTION**: In addition to the familiar site analysis procedures for AC work, working with batteries presents new and unique items which must be considered. Batteries are always live, they can be very heavy, they have unique environmental and chemical hazards. Additionally, DC switches and equipment have unique properties and physical considerations.

**OBJECTIVE:** The purpose of this exercise is to conduct a site analysis or drawing review for a proposed ESS retrofit and to subsequently organize the given steps into a safe and effective method of procedure (MOP).

## Lab 6.2: PPE selection for battery energy storage systems – Contactor replacement

## Lab 9.1: PPE selection for battery energy storage systems – String jumpers

## Lab 9.2: PPE selection for battery energy storage systems – PV voltage

**INTRODUCTION**: Working on battery energy storage systems poses many hazards beyond what is typically encountered during more traditional electrical work. Similar to working with photovoltaics, all energy sources must be considered. Determining and donning the appropriate PPE for these situations and working safely can become challenging due to the multitude of hazards that are encountered and for which the PPE must be rated.

The purpose of these labs is to interpret the provided work order, identify the tasks required to complete the prescribed work, perform the necessary risk and hazard analyses, utilize the hierarchy of risk control methods, and select and don the appropriate PPE for the prescribed tasks.

**OBJECTIVE:** To be able to identify the risks and hazards associated with a provided work order, apply the hierarchy of risk control methods and conduct the applicable risk assessments to select the appropriate PPE required after all control methods are exhausted.

## LAB 10.1: Making Inter-Cell and Inter-Battery Cables (Jumpers)

**INTRODUCTION**: Battery energy storage systems are comprised of strings of batteries stacked in racks. After placing batteries in a rack they must be connected in order to provide power and energy for a required load. The purpose of this lab exercise is to learn how to construct cables with connectors for making such connections.

**OBJECTIVE:** To be able to identify the tools, supplies and PPE needed to construct a cable with connectors according to given specifications. Then construct a cable accordingly.

## LAB 10.2: Making Wet-Cell Intercell Connections

**INTRODUCTION**: Battery energy storage systems are comprised of strings of batteries stacked in racks. After placing batteries in a rack they must be connected in order to provide power and energy for a required load. With wet-cell batteries, each battery often consists of multiple cells per jar. Individual cells may be connected in series and/or parallel.

**OBJECTIVE:** To be able to identify the tools, supplies and PPE needed to install intercell connector plates on a wet-cell battery. Then construct accordingly.

## LAB 10.3: Connecting Batteries (Cells), Checking Polarities and Voltages

**INTRODUCTION**: Batteries (cells) can be connected in series and parallel (series, to build voltage; parallel to build capacity). In doing so shock and arc flash risks increase as connections are made. Therefore, hazard assessments should be performed to understand these risks. Following such assessments, a plan must be developed to mitigate these risks.

**OBJECTIVE:** Connect batteries within each row assembled on a rack.

## LAB 11.1: Making Intertier and Intercomponent Cables (Jumpers)

**INTRODUCTION**: Battery energy storage systems are comprised of strings of batteries stacked in racks. After placing batteries in a rack they must be connected in order to provide power and energy for a required load. Once the string has been connected in series, the intercomponent homerun connection must be made to the first switch and/or overcurrent device. The purpose of this lab exercise is to learn how to construct cables with connectors for making connections between string sections and the homerun cables from positive and negative string leads to a DC disconnect, as well as making those connections.

**OBJECTIVE:** To be able to identify the tools, supplies and PPE needed to construct cables with connectors according to given specifications. Then construct cables accordingly and make connections both between battery strings as well as the positive and negative string leads to a DC disconnect.

## LAB 11.2: Method of procedure for multi-array battery installation

**INTRODUCTION**: As batteries are connected into series and parallel strings and arrays, the voltages and available fault currents grow significantly. The development of a thoughtful method of procedure (MOP) is required to mitigate the hazards that the workers are exposed to. Further, an appropriate MOP can limit the amount of PPE required in order to increase efficiency by not overly encumbering workers.

**OBJECTIVE:** Develop an effective MOP for the installation of series and parallel battery strings for the Building 7R ESS.

## LAB 11.3: PPE Selection for Battery Energy Storage Systems - Handout

**INTRODUCTION**: Working on battery energy storage systems poses many hazards beyond what is typically encountered during more traditional electrical work. Similar to working with photovoltaics, all energy sources must be considered. Determining and donning the appropriate PPE for these situations and working safely can become challenging due to the multitude of hazards that are encountered and for which the PPE must be rated.

The purpose of this lab is to interpret the provided work order, identify the tasks required to complete the prescribed work, perform the necessary risk and hazard analyses, utilize the hierarchy of risk control methods, and select and don the appropriate PPE for the prescribed tasks.

**OBJECTIVE:** To be able to identify the risks and hazards associated with a provided work order, apply the hierarchy of risk control methods and conduct the applicable risk assessments to select the appropriate PPE required after all control methods are exhausted.