FESHM 9170: UNINTERRUPTIBLE ALTERNATING CURRENT POWER BACK-UP SYSTEMS

Revision History

Author	Description of Change	Revision Date
Dave Mertz	• 5-year review and update to 2017 NFPA 70 *National Electrical Code* and 2018 NFPA 70E *Standard for Electrical Safety in the Workplace* in section 2.0 • Added discussion of hazardous energy thresholds to section 4.0. • Added requirements for battery locations to section 4.3. • Added requirements for insulated tools, chemical protection, and maintenance items i to l in section 4.9	5 year review March 2019
Dave Mertz	• Removed references to Interruptible Power Supplies (IPS) except for a definition for existing site equipment labeled as an IPS. • Introduction: Extensively revised. Moved reference to FESHM 6011 to Maintenance and Safety Section • Definitions: Added Battery and Unit Battery definitions, revised definitions of DC Battery Voltage, IPS, and Maintenance Bypass • Requirements: Added requirements 1 and 6, Added requirements for small UPS in requirement 2, added requirement to label panels powered by UPS to requirement 8, allowed partial	June 2014

	electronic documentation in requirement 11. General edits to improve readability and clarity.	

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1.0 INTRODUCTION AND SCOPE

Fermilab utilizes a variety of stored-energy Alternating Current (AC) power systems to provide back-up power to critical loads in the event of power outages. This chapter covers only those systems that employ one or more batteries as the source of the stored power. This type of stored energy system may be combined with another type (typically those driven by internal combustion engines) to economically meet a critical load's requirements. In such a case this chapter covers only the battery system. This chapter uses the term Uninterruptible Power Supply (UPS), to cover battery-based stored-energy systems, including "switched," "line interactive" and "double conversion" system architectures. There are backup power systems that employ kinetic energy storage, typically in the form of flywheels. Due to the rarity of kinetic-energy UPS applications, requirements for their design, installation, and maintenance will be developed on an as-needed, situation-specific basis.

The utilization and maintenance of UPS systems presents a variety of unique safety concerns and hazards. This chapter describes the design and procedural steps to address these concerns.

The Department Head or Appointee will be responsible for assuring that maintenance service and testing is performed.

2.0 DEFINITIONS

Battery is one or more electrochemical cells that provide direct-current (DC) power.

Critical or Standby Power System is a load requirement which provides protection for critical systems such as communications, process loads, spoilage, contamination, hazardous spills or venting, and similar systems which are NOT considered life critical.

Direct Current Battery Voltage – is the nominal rated voltage of the electrochemical cell or battery used, or when two or more cells are connected in series, the quantity of cells connected in series multiplied by the rated voltage of the individual cells or batteries.

Emergency Power System is a back-up power system with loads required for life safety support. This can involve any or all the following: emergency egress lighting, exit signs, ventilation, fire protection, and emergency response. Design requirements generally follow National Fire Protection Association (NFPA) 110A and 111 guidelines.

Equalizing Charge is a charge applied to a battery, which is greater than the normal float charge and it is used to completely restore the active materials in the cell, bringing the cell float voltage and the specific gravity of the individual cells back to equal values.

Float Voltage is a continuous voltage supplying a low current from a battery charger applied to a battery in the standby mode to make up for internal losses and maintain the battery in a fully charged state.

High Current Direct Current Battery Power Source is a low voltage source 12-250 VDC, with a designed or rated output current greater than 100-ampere hours.

Interruptible Power Supply, or IPS, is a designation used by Fermilab to identify an AC battery-supported power supply device intended to provide a backup source of AC power with very short power interruption to the load, which is typically emergency lighting.

Maintenance Bypass is a means of providing NORMAL AC electrical power to the load and isolating the UPS from both the Normal Source and the load. Typically used when servicing or replacing the UPS. Maintenance bypass can be provided by a manual transfer switch which may be open transition or make-before-break design.

National Electrical Code (NEC): The NEC is published by the National Fire Protection Association as NFPA 70. The NEC edition currently adopted by Fermilab is based the more recent of a technical amendment to 10 CFR 851, *Worker Safety and Health* or listed in the contract with the Department of Energy (DOE), and can be found in the Fermilab Work Smart Set of Standards at http://www.fnal.gov/directorate/Legal/files/Appendix_1_v3.pdf. The NEC edition adopted by Fermilab and in effect at the time this Chapter was written is the 2017 edition. All references in this standard to specific articles in the NEC are to those found in the 2017 NEC. If a different edition of the NEC is adopted after this standard is approved, the equivalent article or articles in the presently adopted NEC shall apply. NEC *Analysis of Changes* handbooks published by the NFPA are a useful guide to finding equivalent articles.

Normal Source is the power the UPS receives from the normal AC power distribution system or utility source of electrical power.

Uninterruptible Power Supply is an AC, battery-supported power supply device intended to provide a backup source of AC power with minimal or no power interruption to the connected load.

Unit Battery is a packaged emergency lighting unit that contains a small Unit Equipment UPS sized to power several small lighting loads that are also integral to the package. These small lighting loads typically consist of two incandescent or light-emitting diode floodlamps and may also include an illuminated exit sign.

Unit Equipment is a packaged UPS system as purchased from a vendor or supplier. This includes, but is not limited to, the housing, charger/inverter electronics package, battery package, internal maintenance bypass (when used), internal isolating/protection breakers, internal FAX modem or Ethernet communication module (when used), and self-diagnostics or alarm packages.

3.0 RESPONSIBILITIES

3.1 Department Head

The Department Head or Appointee is responsible for assuring that maintenance service and testing is performed.

4.0 PROCEDURES

UPS system present both alternating and direct current hazards. While NFPA 70E Article 350.9(2) permits the use of 100 volts and 40 mA as the hazardous energy threshold for research and development facilities, because of the mixture of current types in UPS systems and potential for component failures, the more stringent threshold of 50 volts and 5 mA shall be used for all parts of a UPS system, including battery systems.

4.1 Other Codes, Standards, and Regulations

This chapter provides requirements for the design, installation, and operation of AC power backup systems that use batteries. If the requirements of this chapter are in conflict with or do not directly address requirements found in other codes, standards, and regulations applicable to Fermilab, the most stringent requirements shall be followed.

4.2 Design Requirements

For units under 2.5 kiloVolt-Ampere (kVA), plug-and-cord connected Unit Equipment listed by a Nationally Recognized Testing Laboratory (NRTL) shall be used and applied in conformance with their listing. The UPS architecture (switched, line interactive, or double conversion) shall be specified. If Unit Equipment is not acceptable for a specific application, the requirements given below for units rated 2.5 kVA and over shall be applied. Unit Batteries shall be listed by a NRTL and applied in conformance with their listing.

For Units rated 2.5 kVA or more, design requirements shall be developed, which shall include sizing based on the load demand and the duration of the load, the type of power required by the load (frequency, voltage, power factor), the system configuration (UPS architecture, redundancy, transfer features), protective features, limitations of available normal AC power, limitations of available DC sources, short-circuit capability, required controls, instrumentation, and alarms. Refer to American National Standards Institute (ANSI) / Institute of Electrical and Electronic Engineers (IEEE) Standard 944, *IEEE Recommended Practice for the Application and Testing of Uninterruptible Power Supplies for Power Generating Stations*, and IEEE Standard. 446, *Emergency and Standby Power Systems for Industrial and Commercial Applications,* for guidance and criteria for these and other factors to be considered in developing the bases of an UPS system. ANSI/IEEE Standard 944 and IEEE Standard 446 shall be used to develop the bases and requirements of UPS systems with respect to specification of service conditions (environmental), specification of UPS system requirements, and specification of design test requirements. Environmental conditions exceeding the values in ANSI/IEEE Standard 944 should be identified and equipment specifically qualified to these different conditions. Refer to guidance and criteria in NFPA 111 and 110 for the development of bases and specifications for transfer switches to be used with UPS designs.

4.3 Installation

The following factors shall be considered in determining if an UPS installation is acceptable: vibration, temperature, ventilation for hydrogen off gassing and heat removal, local heat sources, power source location, mounting rack (support, insulation, and grounding), seismic needs, and containment for flooded lead acid batteries, instrumentation, and alarms. Refer to IEEE Standard 484 for detailed guidance on battery installation, and to IEEE Standard 450 (lead-acid) and IEEE Standard 1106 (nickel-cadmium) for acceptance testing. Manufacturer's recommendations should be followed, if more limiting, for all batteries, including valve-regulated batteries.

Requirements for Batteries - The specification of requirements for STATIONARY BATTERIES shall include battery load (load profile), voltage, time period, environment, and installation.

Battery Sizing - Battery load profiles and sizing shall be developed in accordance with IEEE Standard 485 (for lead-acid batteries) or IEEE Standard 1115 (for nickel-cadmium batteries). This includes type of load, nature of the load (transient and steady state values), timing of application of loads, length of time for each load and overall time needed for battery operation. IEEE Standard 485 and IEEE Standard 1115 provide detailed instructions on how to treat various types of loads and construct a load profile. Other factors involved in assessing proper battery size include maximum system voltage, minimum acceptable voltage, and battery duty cycle. Cells may be connected in series or series-parallel combinations to arrive at the desired voltage and battery capacity. Refer to IEEE Standard 485 or IEEE Standard 1115 as appropriate for detailed guidance on assessing cell and battery size (number and capacity of cells) and for information on the treatment of design margin and the various associated factors to assess whether sizing is adequate.

Battery Locations – Other than plug-and-cord connected Unit Equipment under 2.5 kiloVolt-Ampere (kVA) listed by a Nationally Recognized Testing Laboratory (NRTL), batteries shall be located in rooms or facilities with adequate illumination for the work to be done, factoring any visual impairment caused by PPE, adequate ventilation to remove excess heat and gasses produced during battery charging and discharging. It may be necessary to retrofit existing facilities or provide dedicated areas in new facilities to safely accommodate battery installations. Access to these locations shall be restricted to authorized personnel by measures appropriate for the location, and access points shall bear signage to indicate the chemical and electrical hazards inside and the required personal protective equipment.

4.4 Power Source Overcurrent and Short Circuit Protection

All UPS units shall be protected with primary side breaker protection and shall be coordinated in accordance with NFPA 110 and the NEC Code. The protection equipment shall not be located in the battery compartment of the enclosure.

4.5 Internal System Protection

All UPS units shall be provided with protection/isolating breakers or fused switches. Units will be installed with adequate ventilation. Only circuits associated with the unit shall be installed in the same enclosure.

4.6 Separation and Protection of Emergency Power System

The wiring for Emergency Power System loads must be kept entirely independent of all other wiring and equipment as required by NEC Article 700.9(B). UPS that supply both an Emergency Power System and other loads must incorporate overcurrent protection devices that will isolate and protect the UPS and the Emergency Power System from faults and overloads in other wiring or equipment as required by NEC Article 700.5(B).

4.7 Connection to Multiple Loads Using Multiple Load Breakers

Use of individual overcurrent load protection devices, such as fuses or circuit breakers, between the UPS power bus and single load taps is often the most practical solution to the safe powering of multiple loads. This permits the safe utilization of conductors more appropriately sized to the individual load and a means to Lockout – Tagout (LOTO) these circuits when necessary. All load branches “fed from” the UPS shall be capable of LOTO isolation - preferably with manufacturer supplied locking hardware.

4.8 Identification and Labeling

All UPS units except cord and plug powered units shall have "fed from" labels on the unit, prominently displayed which indicates the panelboard and circuit breaker supplying normal power and the voltage of the incoming power. A "CAUTION" nameplate is required on the UPS which states that when primary power is disabled, the UPS provides backup power for approximately "XX" minutes. This "CAUTION" nameplate must also indicate that only authorized personnel can perform maintenance or repair service on the unit. Additionally, a telephone number indicating the "responsible party" to call in the event of a problem must be included on the nameplate. Panelboards and similar electrical distribution equipment powered by a UPS shall be labeled “Powered from UPS [insert unique UPS identification]. Do not connect additional loads to this panelboard without engineering approval.”

4.9 Maintenance and Safety

The program should take into consideration the type of service to which the equipment is subjected (duty cycle, chemicals, dust, heat), manufacturers recommendations, and trending.

The requirements for testing, documenting and repairing emergency egress lighting are specifically addressed in and governed by Fermilab Environmental, Safety, and Health Manual (FESHM) Chapter 6011 - “PERIODIC TESTING OF EMERGENCY LIGHTS.”

Maintenance personnel servicing UPS systems must be qualified for that work. Qualifications should be documented and include the following:

a. Fundamentals of electrical and electronic design of the UPS units;
b. Testing and maintenance practices for UPS systems;
c. Specific training on identical or similar equipment to be maintained;
d. Safety precautions for UPS systems; and
e. Facility-specific procedures for operations, surveillance, and maintenance.

Because it is not possible to "turn off" batteries, it is particularly important that tools used to install, maintain, and service battery systems be insulated to prevent inadvertent contact with exposed conductors. Insulated tools marked by the manufacturer with insulation ratings shall be provided by Fermilab or by subcontractor employers to battery system workers. Workers shall inspect insulated tools for damage and wear prior to use.

Batteries often present chemical exposure hazards. Correct procedures and PPE for working with chemical hazards are covered in the Industrial Health FESHM Chapters and the instructions in those chapters shall be followed when working on batteries.

The UPS should be checked for evidence of problems by evaluating meter readings and detrimental environmental problems (e.g., heat, moisture, chemicals). Less frequent activities such as internal cleaning, filter replacement, checking electrical connections for tightness, and calibration shall be done according to manufacturer's recommendations or at intervals not exceeding 18 months. This interval may be reduced according to documented operating experience. An UPS in its standby or normal operating mode may not exercise many of the various features that may be required to function during emergency conditions, such as a loss-of-power or equipment failure. Depending on the design of the UPS system, the following tests should be performed:

a. Light-load Test - operation of controls and instruments for stability and values of voltage and frequency;
b. Synchronization Test - measure the rate of frequency change during Synchronization and UPS voltage during transfer (when an alternate source is part of the design);
c. Alternating Current Input Failure Test - transfers to dc source as designed;
d. Alternating Current Input Return Test - stable return to normal source;
e. Maintenance Transfer Test - forward and reverse (UPS systems using maintenance bypass switches);
f. Rated Full-Load Test - connected or rated load carrying capability for the required duration for extremes of AC and DC input voltage;
g. Output-Voltage Balance Test - measure phase angle and voltage to meet specifications for balanced and unbalanced conditions; and
h. Harmonic-Components Test - measure harmonic content in the output voltage for linear and nonlinear load conditions. The tests above correspond to tests recommended by ANSI/IEEE Standard 944 and should be performed according to manufacturer's recommendations or on at least an 18-month interval.
i. The correct operation of the battery charger and monitoring systems shall be verified no less frequently than annually. It may be worthwhile to interface monitoring systems' alarm or fault indicators with a remote monitoring system so deranged conditions can be detected and corrected more promptly.

j. Battery ventilation openings shall be inspected for lack of obstruction and any caps or flame arresters shall be inspected for condition, correct installation, and proper operation.
k. Inspect battery terminal insulating covers for damage and correct installation.
l. The rooms in which batteries are installed should be checked for proper operation of illumination and ventilation systems when other scheduled UPS maintenance activities are performed.

4.10 Battery Maintenance, Testing, and Surveillance (see reference to Electrical Safety Subcommittee (ESS) Determinations in Additional Design Guidance)

Batteries shall be monitored, periodically maintained, and properly charged to ensure their readiness to perform. Many types of batteries will internally discharge if allowed to sit without a charger, often with irreversible cell degradation. For these types of batteries, it is important to maintain proper charging FLOAT VOLTAGE during standby. Due to inherent differences between cells, FLOAT VOLTAGE and specific gravity values will vary from cell to cell over time. If cell FLOAT VOLTAGES and/or specific gravity values are allowed to remain in an unequal condition for extended periods of time, cell sulfation will result. To overcome this problem, periodic EQUALIZING CHARGE must be applied to equalize cell voltages and specific gravity. Manufacturer's recommendations should be followed in regard to EQUALIZING CHARGE. When performing an EQUALIZING CHARGE, care should be taken to assure the charger voltage does not exceed the voltage rating of the loads connected during the equalize charge. Batteries are rated at a temperature of 25 degrees Celsius. Higher temperatures will improve capacity at high discharge rates but significantly reduce battery life. Lower temperatures will significantly reduce battery capacity. Typical battery types for standby service are lead-acid (calcium, antimony), pure lead (generally a "round cell"), or nickel-cadmium. IEEE Standard 1106 provides criteria and guidance for nickel-cadmium batteries similar to that provided in IEEE Standard 450 for lead-acid batteries. Manufacturers will provide necessary information on the care, precautions, charging, and treatment of specific batteries including during periods of storage.

4.11 Drawings and Records

At least two sets of instruction manuals for the UPS system shall be maintained. The person responsible for coordinating maintenance, service and repair shall have one set, which may be in non-proprietary electronic format such as Portable Document Format (PDF) if stored on a file server with automatic backup, and another set shall be hardcopy located at the unit. They shall contain:

a. A detailed explanation of the operation of the system.
b. A schematic wiring diagram.
c. A functional block diagram.
d. Battery specifications.
e. Material Safety Data Sheets (MSDS) applicable to the installation.
f. All manuals supplied by the manufacturer.

5.0 REFERENCES

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355
356 “Stationary Lead Acid Battery Maintenance and Test Standard”; Lawrence Livermore National
357 Laboratory; Rev.1, April 15, 1993
358 Guide Document “Lead Acid Storage Batteries”; Lawrence Livermore National Laboratory; Rev.2,
359 July 1, 1993
360 Guide Document “Uninterruptible Power Supply (UPS) Systems”; Lawrence Livermore National
361 Laboratory; Rev.1, March 15, 1993
362 **ESS Determination # D2007-3 04-June-2007**
363 http://www-esh.fnal.gov:8001/Electrical/ESS_Determinations.htm

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6.0 TECHNICAL APPENDIX

The maintenance schedule presented in the table below is based on NFPA 111 recommendations for instances in which no manufacturer guidance is available, and should only be used in such situations.

Table A-6-3.2 Solid State Emergency Power Supply Systems Suggested Maintenance Schedule

Item Component (as applicable)	Procedure					Frequency
The suggested maintenance procedure and frequency should follow those recommended by the manufacturer. In the absence of such recommendations, the table below indicates suggested procedures. X Indicates Action R Indicates Replacement If Needed	Visual inspection	Check	Change	Clean	Test	W – Weekly M – Monthly Q – Quarterly S – Semi-Annually A – Annually
1. Battery						
– Float Voltage		X				M
– Cable Connections		X				S
– Terminals				X		Q
– Electrolyte Gravity					X	Q
– Electrolyte Level	X					M
– Replace Cell or Battery			X			See Mfr's Instructions
2. ECE						
– Power Supply Voltage		X				M
– Terminals		X				S
– Panel Meters	X					M
– Panel Lamps	X					M
– Circuit Breakers, Fuses	X	X	R	X		Every 2 Years
3. Battery Charger						
– Output Terminal Volts		X				M
– Fuses	X	X	R	X		Every 2 Years
– Charge Current		X			X	Q
– Equalize Voltage		X				Q
– Panel Meters	X					M
– Panel Lamps	X					M
4. Load						
– Load Current		X				Q
– Panel Meters	X					M
5. Transfer Switch						
– Contacts	X					A
– Test Switch					X	S