

	PRINCETON PLASMA PHYSICS LABORATORY ES&H DIRECTIVES	
	ES&HD 5008 SECTION 2, CHAPTER 6 Capacitors and Capacitor Banks	
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CHAPTER 6 CAPACITORS AND CAPACITOR BANKS

All control and power cables or feeders exiting from areas or spaces having capacitor bank(s) shall be provided with control interlocks, barriers, isolation devices, and shorting or grounding switches to provide full protection to personnel working on the external equipment. Capacitor energy shall be isolated from personnel in accordance with the requirements of Chapter 4.

6. 1 TYPES OF HAZARDS

6.1.1 Capacitors and capacitor banks with stored energy of approximately 10 J or less can constitute a shock hazard. Capacitors and capacitor banks with stored energy of approximately 50 J or more can constitute a lethal shock hazard. The actual degrees of hazard are dependent upon the capacitor or capacitor bank voltages in each application.

Note: Energy storage in a capacitor is determined by the equation:

$$W = \frac{\{C \times V^2\} \times 10^{-6}}{2}$$

Where: W = energy in joules, J (watts-seconds),
 C = capacitance in microfarads (μf), and
 V = potential difference between electrodes in volts (V).

6.1.2. Because of the phenomenon of “dielectric absorption,” all of the charge in a capacitor is not dissipated when it is short circuited momentarily. After the short circuit is removed, a capacitor can re-establish a percentage of its rated voltage sufficient to constitute a safety hazard.

6.1.3. A dangerously high voltage can exist across the impedance of a few feet of grounding cable at the moment of contact with a charged capacitor (i.e., when the capacitor is being discharged by using a grounding-stick).

6.1.4. Discharging a capacitor bank with a grounding-stick can cause a significant electric arc at the point of contact. Such energy can produce thermal radiation and by-products of arcing such as molten metal splatter.

6.1.5. Internal faults may rupture capacitor containers, particularly when parallel-connected capacitors have no individual fuse protection.

6.1.6. Rupture of a capacitor (as by internal electric fault) containing combustible dielectric materials can create a fire hazard.

6.1.7. Polychlorinated-biphenyl (PCB) dielectric fluids can release toxic gases when decomposed by fire or the heat of an electric arc. PCBs are also considered to be a serious environmental contaminant and, as such, their use and disposal are strictly regulated (see paragraph 6.5).

6.1.8. Fuses are generally used to attenuate the discharge of energy from a capacitor bank into a single faulted capacitor. Group fusing of parallel-connected capacitors should not compromise the withstand energy ratings of any individual capacitor.

6.1.9. During transient conditions, capacitors can acquire a charge hazardous to personnel or an over-voltage harmful to the capacitor itself due to the inductance either in the circuit (in the form of coils or magnets) or in the wiring and leakage inductance or both.

6. 2 REQUIREMENTS FOR CAPACITOR BANKS RATED ABOVE 300 V AND/ OR 50J

6.2.1. DESIGN AND CONSTRUCTION CRITERIA

A. All capacitor bank walk-in enclosures shall have a padlock or Kirk ® -type personnel safety interlocks (PSIs). The padlock keys shall be controlled by the cognizant person. The locks shall not be cut open without permission of the cognizant person .

B. An insulating pole (pike type) or other appropriate non-conducting tool, approved by Electrical Safety, shall be provided to separate accident victims from energized equipment. The insulating quality and length of the tool shall be appropriate for the voltage rating of the capacitor bank. The pole, or its equivalent, together with discharge and grounding-sticks, shall be available at the entrance to the capacitor bank. Sticks and poles that are stored at outdoor banks shall have suitable enclosures. Access procedures and drawings shall be readily available. Alternate locations for safety equipment and documentation should be approved in writing by Electrical Safety.

C. Each capacitor bank walk-in enclosure shall have a sign posted at the entrance of the bank stating:

1. The name of the system and its function, as shown on the design drawings.
2. The name and the telephone number of the cognizant person.
3. A list of the persons qualified to provide safe access to the capacitor bank enclosure.
4. The rated voltage of the system.
5. The dielectric fluid in the capacitors (Mineral oil, castor oil, etc.).
6. Whether the rack and capacitor cases are floating or grounded.

D. The design shall require interlocking the capacitor-discharge devices with the circuit breakers or switches used to connect power supplies to the capacitors. The interlocking shall prevent the capacitor-discharge devices from short circuiting the power supply when the circuit breakers or switches are closed, and shall prevent closing a circuit breaker or switch while the capacitors are short circuited. Bleeder resistors shall be installed on all capacitors not having automatic discharge devices.

E. Where appropriate to the design requirements, capacitors shall be provided with current-limiting devices, such as fuses, inductors, and resistors, to interrupt the available fault current or to limit it to a safe value. NEC article 460 contains detailed requirements for sizing conductors and protective devices and must be adhered to.

F. Safety devices, such as shorting switches, grounding switches, buswork, and their associated cables, cable supports, and cable connectors, shall be designed to withstand the mechanical forces due to the largest currents that can result from their operation. See NEC article 460 for detailed requirements.

G. The discharge time constant of current-limited shorting and grounding devices shall be designed to be as small as practicable. See Chapter 4, paragraph 4.15.2, for voltage limits.

H. Grounding-sticks that meet the requirements of Chapter 15, paragraph 15.2, shall be provided in sufficient number to assure that protective-equipment grounding requirements are met.

I. Adequate ventilation shall be provided to keep ambient air temperature at capacitor installations at recommended levels.

J. When fuses are not acceptable for use in a capacitor bank, i.e., when an extremely short discharge time is required, each capacitor shall be installed in a suitable enclosure to provide protection to personnel and equipment in the event of a fault. Enclosures may be used to electrically separate the capacitors into sets that are isolated from each other. The number of capacitors in each set shall be connected so that a faulted capacitor will not receive enough energy (approximately less than 10kJ) from the remaining capacitors in that set to cause it to rupture.

K. Physical and electrical isolation of capacitor banks shall be provided by elevation, barriers, or enclosures to inhibit accidental contact with charged terminals, conductors, cases, or support structures. Enclosures and barriers shall be designed to protect personnel from projectiles, such as bushings and terminals, that may be expelled during a fault.

L. If a hazards assessment indicates that a potential exists for rupture, then the fault energy of the hazards assessment calculations should be used to select adequate barriers to protect personnel from projectiles and shrapnel. Barriers or protective devices (or some combination of these) may be used if engineering analysis determines them to be adequate to protect personnel from potential hazards.

6.2.2 OPERATING CRITERIA

A. Access to capacitor walk-in enclosures shall be restricted through the use of Padlocks or kirk key interlock PSI's. The keys to these padlocks shall be controlled by the cognizant person and shall be issued only to those individuals authorized to carry out the safety-access procedure. Capacitor walk-in enclosures shall not be declared a General-Access area for use by other than Qualified Personnel until all capacitors have been discharged, shorted, and grounded in accordance with the procedures in the following paragraphs B through R.

- B. A specific, detailed, written “safing” (making safe) procedure, concurred with by the Head of ES&H or designee, shall be provided and kept current by the cognizant engineer for each capacitor bank. It shall describe the steps to be taken to make the area and capacitor bank safe. A copy of this procedure shall be available with the personal protective equipment.
- C. Before personnel may be placed on the list of individuals authorized/qualified to carry out the safing (making safe) access procedure, they shall read and sign the procedure, indicating that they read and understand it. They shall be trained in the procedure at least once by someone already on the list. Their supervisor shall approve their addition to the list, indicating that they are fully capable and adequately trained. Capacitor bank access training per the respective capacitor bank access procedure must be renewed every 3 years and witnessed by ES & H Division Head or designee; In addition, the General Capacitor Bank Access training course shall be taken one time and the Basic Electrical Safety training is required and shall be renewed every 3 years.
- D. Only persons authorized in accordance with paragraph 6.2.2.C may initially enter a capacitor bank enclosure and at least two such persons shall be present. As the first person enters, the second person becomes the Safety Watch (qualifications and responsibilities are listed in Chapter 2, paragraph 2.2.6). The Safety Watch shall prevent other people from entering the capacitor bank enclosure until safing is complete.
- E. Before entering a capacitor bank enclosure, the Safety Watch and Qualified Personnel must assure that emergency communication can be established either by telephone, intercom, or, by radio in more remote areas. The means of emergency communications shall not require that the Safety Watch leave the observation position and the communication equipment shall be checked to assure that it is operational.
- F. The Qualified Personnel shall use the appropriate personal protective equipment as specified in the Access procedure for their respective capacitor bank. A second set of personal protective equipment shall be available for use by the Safety Watch.
- G. Safe/Access procedures, electrical schematic diagrams, and operating instructions shall be available at the entrance to the capacitor area and shall be kept up-to-date by the cognizant person when performing the accessing of the capacitor bank .
- H. Positive zero voltage verification is required prior to starting to ground the capacitors. Remove any residual charge from capacitors by grounding the terminals with a high-impedance and then a low-impedance grounding-stick in accordance with the safing procedure described in paragraph 6.2.2.B.
- I. Before working on capacitors, they shall be shorted and grounded as required by the capacitor bank safing procedure for the specific bank and as described in paragraph 6.2.2.B.
- J. Do not rely exclusively on automatic discharge and grounding devices for personnel safety.

Grounding-sticks shall be used.

K. Capacitor cases, unless obviously connected to a recognized grounding conductor or grounded structure, shall be considered charged. They shall be grounded for personnel safety according to procedures described in paragraph 6.2.2.B. Ungrounded capacitor cases shall be properly labeled, with their operating voltages identified.

L. Operating personnel should stand clear of cables attached to grounding-sticks at the moment of application to a capacitor terminal and should be prepared for high currents and resulting forces, arcing, and molten metal resulting from the arc.

M. The Safety Watch shall determine when the safing procedure has been satisfactorily completed. When completed, a dedicated Safety Watch is no longer required.

N. Working alone is prohibited in a capacitor area until it is rendered a General-Access area in accordance with Chapter 4, paragraph 4.12.1. The Safety Watch shall declare when the capacitor area is open to "General Access".

O. Annually inspect all personnel-protective grounding devices to verify proper operation. Repair any defects that are found, then clean and notify Electrical Safety to have testing performed.

P. Each time the bank is accessed, inspect capacitors for leaking or deformed cases and check for defective lighting in the area. Report lighting defects to the PPPL Maintenance and Operations (M&O) Division, and coordinate area access with M&O for repair.

Q. Short circuit capacitors in storage with a conductor (approximately a No. 14 AWG) securely fastened to the terminals and left in place until the capacitors are returned to service. If a capacitor is scheduled for disposal, the short circuits shall remain in place.

R. The cognizant engineer and Electrical Safety shall inspect the bank and certify the accessors prior to initial operation of an energy-storage installation and re-certify them prior to its operation after significant changes have been made. ES&HD Form No. 5008-2.2 CBI (Chapter 17, Attachment D) shall be completed and filed by the Electrical Safety inspector.

S. In the event of an emergency, immediately call ESU at ext. 3333.

6.3 REQUIREMENTS FOR CAP BANKS RATED 300 V & UNDER, 10 J TO 50 J

6.3.1. Electrical control interlocks shall automatically turn off power supplies and discharge the capacitors under abnormal conditions and upon the opening of any entrance associated with the capacitor bank.

6.3.2. Entrances shall be padlocked. Access shall be determined by operating personnel.

6. 4 REQUIREMENTS FOR CAPACITOR BANKS RATED UNDER 50 V AND 10 J

Capacitor banks with voltages less than 50 V and less than 10 J, and corresponding cables or feeders, are not required to have electrical control-interlocks or padlocks.

6. 5 REQUIREMENTS FOR PCB CAPACITORS

- A. PCB capacitors may not be moved or disposed of without the coordination and approval of the PPPL Materiel and Environmental Services Division (M&ES).
- B. Any leaks of PCB fluids must be reported immediately to the PPPL Emergency Services Unit, Ext. 3333.
- C. All PCB capacitors that are not in service shall be removed. Contact M&ES for removal of all PCB and other types of capacitors. If assistance is needed to determine if the capacitor contains PCB's, contact M&ES at ext. 2213 or 3380.
- D. No PCB capacitors shall be procured at PPPL.