IEEE Recommended Practices for Safety in High-Voltage and High-Power Testing

Sponsor

Power System Instrumentation and Measurements Committee of the IEEE Power Engineering Society

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IEEE Standards Board

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Foreword

(This Foreword is not a part of IEEE Std 510-1988, IEEE Recommended Practices for Safety in High-Voltage and High-Power Testing.)

Safety is of major importance and should be of major concern to all who are involved in high-voltage and high-power measurements. Most organizations and individuals who are involved in such measurements already have a system of safety rules. This recommended practice is intended to provide guidance for those who are establishing or revising their safety rules. This recommended practice has been developed to cite some of the hazards present in making high-voltage and high-power measurements, and some of the procedures and equipment which can be used to reduce personnel hazards. It is important to recognize that procedures and equipment cannot provide complete safety; the individual's attitude is the key to safety.

This recommended practice was prepared by the Safety Practices in High-Voltage Measurements Working Group of the Power System Instrumentation and Measurements Committee of the IEEE Power Engineering Society.

J.A. Staley served as the first chairman of this working group and was instrumental in guiding development of this recommended practice through the first three drafts.

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CLAUSE PAGE

IEEE Recommended Practices for Safety in High-Voltage and High-Power Testing

1. Scope

This recommended practice is concerned with safety practices for those who are involved with making measurements on high-voltage sources or with high-power sources of various types including power-system lines, 60 Hz test transformers, direct-voltage supplies, lightning-impulse generators, and switching-impulse generators. This recommended practice is limited to safety practices with regard to electrical hazards involved in temporary measurements, as opposed to metering, relaying or routine line work.

Considerations of safety in electrical testing apply not only to personnel but to the test equipment and apparatus or system under test. This recommended practice deals generally with safety in connection with testing in laboratories, in the field, in substations and on lines, and with the test equipment utilized. Special areas involving cable-fault location, large capacitance load testing, high-current testing, and direct connection to power lines are treated separately. For applications of high-voltage test equipment and methods in areas not specifically covered, the following general guides apply:

1) All ungrounded terminals of the test equipment or apparatus under test should be considered as energized.
2) Common ground connections should be solidly connected to both the test set and the test specimen. As a minimum, the current capacity of the ground leads should exceed that necessary to carry the maximum possible ground current. The effect of ground potential rise due to the resistance and reactance of the earth connection should be considered.
3) Precautions should be taken to prevent accidental contact of live terminals by personnel, either by shielding the live terminals or by providing barriers around the area.
4) The circuit should include instrumentation for indicating the test voltages.
5) Appropriate switching and, where appropriate, an observer should be provided for the immediate deenergization of test circuits for safety purposes. In the case of dc tests, provisions for discharging and grounding charged terminals and supporting insulation should also be included.
6) High-voltage and high-power tests should be performed and supervised by qualified personnel.
7) Consideration should be given to safety regulations which may apply to specific circumstances; for example, other IEEE guides, union, company, or government regulations (see also Appendix B).
8) In the use of signal-gathering equipment, each device should be used in such a manner that it will not present a personnel hazard should it inadvertently become a part of the high-voltage circuit, or fail to function properly.

2. References

[1] ANSI C2-1981, National Electrical Safety Code.[1]

[2] ANSI C39.5-1974, Safety Requirements for Electrical and Electronical Measuring and Controlling Instrumentation.

[3] ANSI Z89.1-1981, Protective Headwear for Industrial Workers.

[4] ASME 1980 Boiler and Pressure Vessel Code, Section VIII, Pressure Vessels,[2] Division 1

[5] IEC 348-1978, Safety Requirements for Electronic Measuring Apparatus.[3]

[6] IEEE Std 80-1976, IEEE Guide for Safety in AC Substation Grounding.

[7] OSHA 1910.145, Specifications for Accident Prevention Signs and Tags.[4]

3. Definitions

high-voltage: For the purposes of this recommended practice a voltage of approximately 1000 V has been arbitrarily assumed as a practical minimum for these types of tests. It is further assumed that the voltage source has sufficient energy to cause injury.

Individual judgment is necessary to decide if the requirements of this recommended practice are applicable in cases where lower voltages or special risks are involved

high-power: For the purposes of this recommended practice high-power testing shall refer to testing conducted in laboratories and in the field where fault currents, load currents, magnetizing currents, and line dropping currents are used to test a product, either at rated voltage of the product or at lower voltages.

power system: An established and permanent electrical power-supply system operated by a public or private utility company or a large industrial organization.

mobile: Equipment which is readily moved to the place of operation but not carried by hand. Where the equipment is mounted in or on a vehicle this specification applies to the entire vehicle.

permanentlyinstalled: Equipmentwhichispermanentlyinstalledattheplaceofoperation,andhaspermanentpower input and grounding connections.

operators: Personnel who carry out high-voltage testing or high-power testing, or both.

observers: Personnel who are responsible for observing and reporting the effects of a test or observing a specific safety hazard and giving warnings as required.

test coordinator: A person who has overall control of a test.

qualified personnel: Personnel who have been trained in correct and safe methods.

[1]ANSI standards are available from the Sales Department of American National Standards Institute, 1430 Broadway, New York, NY 10018.
[2]ASME standards are available from the Sales Department of the American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017.
[3]IEC Standards are available in the US from the Sales Department of American National Standards Institute, 1430 Broadway, New York, NY 10018.
[4]OSHA documents are available from the Superintendent of Standards, US Government Printing Office, Washington, DC 20402.

4. Hot Line Tools and Rubber Protective Equipment

1) Adequately rated insulated equipment should be used when switching or maintaining electrical equipment while it is energized. Electric equipment and lines should be considered energized until determined to be de-energized by tests or other appropriate methods or means.
2) Rotating machinery should be considered energized even when unexcited, due to the residual magnetism which may produce hazardous voltages at the terminals of the machine.
3) Rubber-protective equipment should be in accordance with the provisions of National Consensus Standards with regard to such protective devices as rubber-insulating gloves, matting, blankets, hoods, line hoses, and sleeves.

5. Safety Practices — Laboratory Work

5.1 Test Areas

5.1.1 Permanent Test Areas

Permanent test areas should be completely enclosed by walls or some type of physical barrier. Entrances to such areas should be interlocked with the high-voltage power supplies so that test voltage cannot be applied while the gates are open.[5]

Appropriate warning signs, for example, DANGER — HIGH VOLTAGE, should be posted on or near the entrance gates. (Refer, for example, to OSHA 1910.145 [7] for colors, proportions and composition.)

In some cases it is necessary to operate permanent test areas without completely enclosing barriers. In such cases the procedures for temporary areas should be used.

5.1.2 Temporary Test Areas

Temporary test areas should be completely enclosed by some type of barrier. Some examples are:

1) Portable fencing which is grounded and equipped with interlocked entrances (see 5.4.1).
2) Distinctively colored safety tape supported approximately waist high to which suitable safety signs (see 5.1.1) are attached. No one may cross this barrier. When the test is completed and the test voltage has been removed, the tape must be removed before anyone may enter the area. Alternatively, a gate carrying a suitable warning sign can be made in the tape barrier with the tape or *tennis* netting. This gate can be opened only after test power has been removed. If possible, this gate should be interlocked or an operator-activated foot switch interlock should be used.
   If the taped-off area cannot be viewed completely by the operator, one or more observers should be stationed so that the entire area can be monitored. A taped-off area should never be left unattended while the test power is on.
3) A loud speaker system is sometimes desirable for the purpose of communicating with all personnel in the area.

5.2 Interlock Systems

Interlock systems should be designed where possible to be *fail-safe*. Where this is not possible, visual or audible signals should be provided to warn personnel of system malfunctions. (See Appendix A for some examples of typical interlock systems.)

[5]The numbers in brackets correspond to the references listed in Section 3 of this standard.

5.3 Access to Test Areas

A systematic procedure must be developed and implemented to control access to the test areas so that an area will not be energized with a person in it. A key switch system for accomplishing this is detailed in Appendix A. In special cases it may be necessary to place an observer within a test area. This should be done only after special permission has been granted and a safe working procedure has been established. This procedure may be patterned after those given in 5.1.2. Alternatively, it involves placing the person within or behind a grounded barrier or having him sit or stand on a special switch which removes the high voltage if he moved off the switch. The wiring to such a switch should conform to 5.5.2.

5.4 Safety Within Test Areas

5.4.1 Grounding Practices

All specimens should be properly grounded so that personnel hazards do not exist. It is necessary to ground the high-voltage circuit before working on it or on the test object.

Insofar as practical, automatic grounding devices should be provided to apply a visible ground on the high-voltage circuits after they are de-energized. In some high-voltage circuits, particularly those in which elements are changed from one setup to the next, this may not be feasible. In these cases the operator should attach a ground to the high-voltage terminal using a suitably insulated handle. In the case of several capacitors connected in series, it is not always sufficient to ground only the high-voltage terminal. The exposed intermediate terminals should also be grounded. This applies in particular to impulse generators where the capacitors should be short-circuited and grounded before and while working on the generator.

Safe grounding of instrumentation should take precedence over proper signal grounding unless other special precautions have been taken to ensure personnel safety.

All conductors and cables used for grounding should be of an electrical size capable of handling the maximum possible currents.

5.4.2 Direct-Voltage Power Supplies

Due to the dangerous nature of the residual charge which may exist on high direct-voltage power supplies, on ungrounded capacitive elements, and on ungrounded metallic objects, the following safety procedures should be adhered to:

1) Prior to energizing a direct voltage power supply, personnel in adjacent test areas should be alerted since dangerous charges can be induced on ungrounded capacitive elements and ungrounded metallic objects. Such capacitive elements and large metallic objects, both in adjacent test areas and in the immediate areas, should be short-circuited and grounded before energization of the direct voltage.
2) After de-energization, the test voltage should normally be allowed to decay to a low value before personnel enter the area. However, in special cases it is permissible to enter the area immediately, providing the ground stick [see 3.4.2(3)] is long enough to reach the high-voltage terminal without endangering the operator.

Upon entering the area, the first action taken should be to place a ground on the high-voltage terminal and any other exposed terminals. A grounding conductor with a suitably insulated handle should be used for this purpose.

NOTE — In the case of high-capacitance specimens such as long cables or large rotating machines, the initial grounding should be accomplished through a resistor followed by a direct ground. In some cases the direct ground should be left in place far an extended period of time (see 5.1).

5.4.3 Physical Hazard

High-voltage testing and high-power testing give rise to the following unusual hazards. (See also 5.3.2.)

1) Attention should be given to the possibility of flying porcelain or other materials in the event of a failure.
2) Large open top oil tanks present a drowning hazard. Because of the different densities of insulating oil and water, it is prudent to assume that even those who are expert swimmers in fresh or salt water will find it impossible to swim in oil.

5.5 Control and Measuring Circuits

5.5.1

Leads should not be run from a test area unless they are contained in a grounded metallic sheath and terminated in a grounded metallic enclosure, or unless other precautions have been taken to ensure personnel safety. Control wiring, meter connections, and cables running to oscilloscopes fall into this category. Meters and other instruments with accessible terminals should normally be placed in a metal compartment with a viewing window. Interlocks should be provided to interrupt the power supply if the compartment cover is opened. The cases of oscilloscopes should be connected to the nearest ground at their location unless other precautions have been taken to ensure personnel safety.

5.5.2 Current and Voltage Measuring Devices

1) The secondary terminals of a current transformer should never be left open circuited.
2) Switching of current transformers should be by means of a make-before-break switch or equivalent means.
3) Current transformers should be properly grounded when in use.
4) Current transformers and potential measuring devices should be properly insulated for the voltage of the supply.
5) The voltage transformer secondary or output and the transformer frame should be properly grounded. When capacitor-fed devices are used, the zero-potential terminal of the capacitor-fed network must be grounded. The output or measuring circuit should be properly grounded and fused near the device.
6) It is good practice to use a properly sized surge-protective device to protect the instrumentation and circuitry.

5.5.3 Temporary Circuits

Temporary measuring circuits should be located completely within the test area and viewed through the fence. Alternatively, the meters may he located outside the fence, provided the meters and leads, external to the area, are enclosed in grounded metallic enclosures.

Temporary control circuits should be treated the same as measuring circuits, and housed in a grounded box with all controls accessible to the operator at ground potential.

Whenever possible, maintenance service cables and conductive hoses should be run into a test area through an open gate. They must be removed before the gate may be closed. If the cables or hoses must be run into the area by some other path, special precautions, such as tagging the gate with an appropriate warning, should be taken to ensure that they are removed before the area is energized with high voltage.

5.6 Safety Rules

A set of safety rules should be established and enforced for the laboratory or testing facilities. A copy of these should be given to, and discussed with, each person assigned to work in a test area. A procedure for periodic review of these rules with the operators should be established and carried out.

5.7 Safety Inspection

A procedure for periodic inspection of the test areas should be established and carried out. The recommendations from these inspections should be followed by corrective actions for unsafe equipment or for practices that are not in keeping with the required regulations.

NOTE — A safety committee composed of several operators appointed on a rotating basis has proven to be effective, not only from the inspection standpoint but also in making all personnel aware of safety.

5.8 Additional Precautions

The precautions outlined in Section 7 may also be appropriate.

6. Safety Practices in the Field

This section provides guidance in recognizing and avoiding hazards that may arise from the conduct of high-voltage tests and measurements outside the controlled environment of a laboratory. It is not intended to constitute rules such as may exist in established codes of work practices nor to delineate mandatory requirements such as may be specified in national or regional codes for electrical safety. (Refer, for example, to ANSI C2-1981, Part 4, [1], Rules for the Operation of Electric-Supply and Communications Lines and Equipment.) Personnel engaged in field testing should be thoroughly conversant with the appropriate work rules and safety codes, and with the equipment to be used.

The scope excludes measurements made with permanently installed instrumentation. Also excluded are specific procedures (for example, phasing out, and testing for no voltage) which are routinely made by qualified operators under appropriate rules of work practice.

6.1 Field Tests — General

6.1.1

Since the environment in which field tests are conducted differs in important respects from that of the laboratory tests, extra care should be taken to ensure appropriate levels of safety.

Permanent fences and gates for isolating the test area are not usually provided, nor is there permanent conduit for the instrumentation and control wiring. Further, there may be sources of high-voltage electrical energy in the vicinity in addition to the source of testing voltage.

1) In all cases there should be a single person responsible for the conduct of the tests and for the dissemination of necessary safety instructions to the personnel involved. This is a minimum requirement. (Refer to 6.2.4 and 6.2.5 for more elaborate or complex tests.)
2) The considerations given in this section provide guidance in achieving a level of safety in field testing comparable to that achieved in the laboratory. It is to be emphasized that assurance of safe conditions must be rooted in the safety-oriented attitude of all personnel involved in the testing.

6.1.2

It is usual that when an energized power system is involved in or is close to the testing operation, a formal procedure for granting permission to work will exist for the purpose of ensuring safe disconnection of sources of system power at the test location. Such procedures may, in any particular case, be considerably more elaborate than those mandated by the applicable national consensus standard. (Refer to ANSI C2-1981, Part 4, Rules for the Operation of Electric-

Supply and Communications Lines and Equipment, [1]. The requirements of the consensus standard represent minimum precautions to be observed with respect to the sources of system power.

1) It should be realized that a permit to work, in accordance with the relevant standard, does not relieve any individual involved from personally ensuring the safety of himself, of the other personnel involved in the test, and of any persons who, for other reasons, may be in proximity to the test site.
2) When working in the vicinity of energized conductors, the clearance mandated by the appropriate national or regional code for electrical safety must be maintained. (Refer to ANSI C2-1981, Part 4, Rules for the Operation of Electric-Supply and Communications Lines and Equipment, [1].)

6.1.3

The precautions necessary for protection of personnel end equipment from the hazards of the high-voltage or high-power testing must be observed for every test. Since tests performed in the field may range from simple tests on isolated pieces of equipment to complex staged tests employing system power integrated with test voltages, this recorded practice cannot cover every specific case.

1) The required testing should be accomplished in accordance with the appropriate test codes or guides.
2) In addition to the person controlling the application of voltage or current, at least one other person should be capable, either by communication, direct action, or remote control of interrupting the testing in the case of unexpected events
3) Definite procedures should be formulated for dealing with the consequences of possible failure of the apparatus under test

6.1.4

In the more elaborate or complex instances of field testing, a test coordinator should be designated to manage the coordination of test procedures with the relevant system safeguards. The test coordinator should have a complete familiarity with the test equipment, and should be guided at all times by the necessity of ensuring safety to the personnel and to the test equipment, and of maintaining the integrity of the power system.

The test coordinator should be responsible for formulating a set of rules and a system of compliance which will provide safeguards to personnel comparable to that provided by permanent *permission to work regulations*.

6.1.5

When complex staged tests are contemplated, consultation and coordination with the appropriate persons responsible for engineering, operating, and maintaining or constructing the system should be initiated well in advance of the proposed testing, and should be carried out in sufficient detail so that a possibility of unsafe conditions or of impossible-to-execute procedures will not be encountered during the testing.

1) Special settings of protective relays and re-examination of backup schemes may be necessary to ensure an adequate level of safety during the tests, or to minimize the effects of the testing on other parts of the power system.
2) The test coordinator should personally ensure that all special devices or settings are applied before initiating the test procedure.
3) The possible occurrence of unusual phenomena such as ferroresonance, neutral inversion, and self-excitation of rotating machinery, should be carefully considered, and specific plans for dealing with the hazardous voltages that could develop in such cases should be formulated in advance.

6.2 Isolation (Roping-Off) of the Equipment Under Test — Field Conditions

6.2.1

The purpose of isolating areas is to avoid the presence of persons in a region where high-voltage hazards exist. It is not always possible in the field to physically prevent ingress of persons into a test area, as is accomplished by the fences and interlocked gates of the laboratory environment. Instead, readily recognizable means are employed so as to actively discourage such ingress.

The effectiveness of such means depends upon respect for their significance, a respect which is largely a matter of discipline. Such discipline should be rigorously enforced.

The effectiveness of the means employed can be severely compromised by inattention to the necessity for removing them when they are not required. For example, to leave barriers in place for a week at a time when testing is performed only an hour or two per day is likely to result in disrespect.

Typical devices and schemes are discussed below for expository purposes. In any given organization, those barriers which are traditional are most likely to be respected. In all cases, enough warning signs to be visible from all approaches should be part of the barrier system. (see 3.1.1.)

6.2.2

Roping-off the area with a distinctive flexible safety line (for example, yellow-and-black polypropylene rope or orange fabric tape) is probably the most widely used means of isolation employed for hazardous areas in a power system. This method may be combined with the use of traffic cones and flags.

6.2.3

Street barriers of the saw-horse type are commonly used at construction sites which are partially energized. Such barriers may be augmented by safety ropes, traffic cones, etc.

6.2.4

Portable electrically-interlocked stanchions or pylons, usually with warning lamps appropriately illuminated, and sometimes with audible warning devices, are a more elaborate means of isolating a test area under field conditions. A flexible cord with plugs and receptacles is used to interconnect the devices around the perimeter of the test area. Considerations appropriate to the design of a safety interlock system are discussed in Appendix A.

6.2.5

Both the person responsible for the testing and the person operating the test equipment should satisfy themselves by making sure that all necessary barriers are in place before test potential or current is applied. It should be determined that all persons likely to be in the vicinity are familiar with the significance of the barriers. In many circumstances, a guard or safety supervisor may be necessary.

6.3 Grounding in the Field

6.3.1

Test equipment and test specimens should, in most cases, be properly grounded prior to making or breaking any test connections. Careful consideration should be given to possible induction from nearby conductors.

1) Grounding or short-circuiting jumpers under the control of the test coordinator should be applied to the appropriate terminals or conductors. Such jumpers as are necessary to maintain a safe ground should be in place before permanent connections are disconnected. The jumper connections should be reliable for the service involved. Clamp-type connections are recommended and devices such as *alligator* clips are deprecated.
2) At the conclusion of testing, the conductors and apparatus should be returned to normal condition, with all temporary connections, and grounding, and short-circuiting jumpers removed.
3) When the testing results in the accumulation of electrostatic charge on the apparatus, short-circuiting or grounding jumpers, as appropriate, should remain in place for a time sufficient to reduce the charge to a nonhazardous level.

6.3.2

Safe grounding of instrumentation should be ensured. This may require the use of triaxial or shielded twin-conductor cable rather than the more usual coaxial cable, or the use of differential-input measuring devices, so that the exposed parts of instruments can be bonded to the nearest local ground, independent of the location of the signal ground. When local grounding of exposed parts is not feasible, they either should be effectively isolated from personnel, or both personnel and instrumentation should be in an electrically-bonded environment that is electrically isolated from the ground.

6.3.3

Any ground conductor that may be called upon to handle fault current in achieving its protective function should be of adequate electrical size to safely conduct the maximum possible fault current.

1) All ground-conductor connections should be of such construction as to safely and reliably conduct the maximum possible currents.
2) Ground conductors should be identified by a mark or a color code, unless it is otherwise obvious.
3) In all applications, the ground end of ground conductors must be connected first and disconnected last.

6.3.4

Careful consideration should be given to the possibility of voltage gradients developing in the earth during impulse, short-circuit, inrush, or oscillatory conditions. Such voltages may appear between the feet of an observer, or between his body and a grounded object, and are usually referred to as step and touch potentials. Extensive coverage of this problem is available in other guides or codes (Refer, for example, to IEEE Std 80-1976 [6] and ANSI C2-1981, Section 9 [1]).

1) Observers and test personnel who may be exposed to such potentials should be protected by establishing an essentially equipotential safe area, either by adequate bonding or by effective insulation. In the design of the protection cognizance should be taken of the magnitude and the rate of change of current. Alternatively, the affected area can be isolated from personnel.
2) Even when *step* and *touch* potentials are not considered to present a recognizable hazard, it is good practice for personnel to observe the precautions of keeping their feet close together and of avoiding contact with conductive objects during the application of test voltage or current.
3) When high currents are intentionally employed in the testing, consideration should be given to providing an isolated ground-return conductor adequate for the service so that no intentional passage of heavy current, with its attendant voltage rise, is permitted in the ground grid or in the earth.
4) Keep signal, ground, and power cables separate.

6.3.5

If test trailers or vans are used, the chassis should be grounded. Adequate bonding of chassis, instrument panels, and other conductive parts accessible to personnel should be provided. If hazardous touch potentials can reasonably be expected to develop with respect to the vehicle, protection should be provided either by bonding, insulation, or isolation.

1) Protection by bending can be effected by providing around the vehicle an area covered by a metallic mat or mesh of substantial cross-section and low impedance which is bonded to the vehicle at several points and is also bonded to an adequate number of driven ground rods or to an adequate number of accessible points on the station ground grid. All bending conductors should be of electrical size adequate to keep the voltage developed under maximum anticipated current to a safe value. The physical extent of the mat should be sufficient to preclude simultaneous contact with the vehicle and with the earth or with metallic structures not adequately bonded to the mat.
2) Protection by insulation can be accomplished, for example, by providing around the vehicle an area of dry wooden planks covered with tested rubber blankets. The physical extent of the insulated area should be sufficient to prevent simultaneous contact with the vehicle or the ground lead of the vehicle, and with the earth or with metallic structures in the vicinity.
3) Protection by isolation can be implemented by providing effective means to exclude personnel from any area where simultaneous contact can be made with the vehicle (or conductive parts electrically connected to the vehicle) and with other conductive materials. A combination of barriers such as those discussed in 6.2, together with effective, preferably interlocked, restraints on inadvertent exit from the vehicle during the testing may be employed.

6.4 Signal Measuring Equipment and Connections

6.4.1 Current and Voltage Measuring Devices

1) For general considerations, refer to Section 1 (8) and 5.5.3.
2) When synchronizing or similar circuits are present on the low-voltage side of measuring devices, the possibility of back-feeding high voltage from secondary energization should be carefully assessed and appropriate safety precautions taken.

6.4.2 Instrument and Control Wiring

1) The insulation of temporary wiring, test switches, etc, associated with the testing should be adequate for the common-mode, induced, and transient voltages that may occur, so that personnel are not exposed to hazards arising from insulation failure (see 6.3.2).
2) The routing and connections of temporary wiring should be such that they are secure against accidental interruptions that may create hazard to personnel or equipment.

7. Areas of Special Concern

7.1 Cable and High Capacitance Testing

High-voltage testing of objects having high capacitance is an area of special concern. This is particularly true in dc proof testing and capacitive discharge fault locating. In both of these situations special precautions may be required. The requirements of Sections 5 or 6, as appropriate, should also be considered.

7.1.1 General Procedures

1) Devices which rely on a solid or solid/ liquid dielectric for insulation should preferably be grounded and short-circuited when not in use.
2) Good safety practice requires that capacitive objects be short-circuited in the following situations:

a) Any capacitive object which is not in use but may be in the influence of a dc electric field should have its exposed high-voltage terminal grounded. Failure to observe this precaution may result in a voltage induced in the capacitive object by the field.

b) Capacitive objects having a solid dielectric should be short-circuited after dc proof testing. Failure to observe this precaution may result in a buildup of voltage on the object due to dielectric absorption in the insulation. The short circuit should remain on the object until the dielectric absorption has dissipated or until the object has been reconnected to a circuit.

NOTE — It is good practice for all capacitive devices to remain short-circuited when not in use.

c) Any open circuited capacitive device should be short-circuited and grounded before being contacted by personnel.

7.1.2 DC Proof Testing

1) DC proof testing requires special consideration (see 5.4.2.).
2) DC proof testing requires very little current, on the order of a few milliamperes. However, this low current applied to a test object of appreciable capacitance, will result in a substantial amount of energy being stored in the test object as the voltage builds up over a period of time. This stored energy requires the same respect due to any low impedance source of high energy.
3) Because of the stored energy referred to in 7.1.2 (2), arrangements should be made so that the source of high voltage is not damaged or does not create a hazard when the source is switched off or the test object breaks down. DC high-voltage test equipment usually has some resistance in series with the output. It is also common practice to include a grounding switch which shunts the high-voltage terminal to ground when power is switched off. In some cases this grounding circuit may be accidentally activated, for example, by loss of input power. If there is any question about the ability of these components to handle the stored energy, a suitably rated external series resistor should be used to reduce the discharge current to a safe value.
4) Test objects having large capacitance may require appreciable time to discharge through the test set impedance. If an external ground is to be applied to the test object to remove the stored charge, this ground should be applied initially through a properly rated resistor.

   NOTE — The shorter the time constant of the discharge circuit, the higher the temperature discharge resistor must withstand. Resistors of identical power rating may differ in thermal mass. Resistors used in fast discharge circuits should therefore have an adequate energy rating.
5) At the completion of a dc proof test the voltage should be allowed to bleed down to a value consistent with the capability of the grounding device. When the test object has fully discharged a short circuit should be applied (see 7.1.1).
6) In performing an overvoltage test on an installed cable, particular attention should be given to isolating the cable ends from the power system. It should be borne in mind that the combined stress of the applied test voltage, the power frequency voltage on the hot side of the disconnect switch, and the possible switching transients on the power frequency line may overstress the disconnect switch. Barriers and an observer may be required at the remote end of the cable under test.

7.2 Cable Fault Locating

7.2.1 Capacitor Discharge Method

1) Cable fault location by the capacitor discharge method requires special consideration because of the energy involved, and also because the electrical circuit is almost always physically large. When both of these conditions are present, the recommendations of this section are especially important.
2) A capacitor discharge fault locating system typically generates high-voltage pulses having fast rise times and appreciable energy. The energy available from the capacitor discharge source requires that this source be handled with the same care as other low impedance sources of high energy. The fast rise-time of the high-voltage pulses produced by this class of equipment requires additional precautions.

   a) The rate of rise of voltage in the output pulse of a capacitive discharge-test set can cause the voltage of normally grounded structure to rise above ground. Good practice requires that conducting objects in the vicinity of the operator be securely connected to ground.

b) If the capacitive discharge equipment is not locally grounded, which may be the case where a system is installed in a trailer or truck, precautions should be taken to prevent personnel on the ground from contacting the structure to which the equipment is grounded. Alternatively and preferably, a local driven ground should be established (see 6.3.5).

7.2.2 Earth Gradient Method

Earth gradient types of fault locators are frequently used for direct buried cables. As the name implies, these systems rely on a voltage gradient along the ground return in localizing a fault. These systems are usually designed to be portable to facilitate fault location. It is therefore imperative that a local ground be established at the point at which the system is to be operated to ensure operator safety. Reliance on the ground normally provided in the input power cable may result in serious injury (see 8.2.2 and 8.6.3)

7.3 High-Power Testing

High-power testing involves a special type of high-voltage measurement in that the level of current is very high. Careful consideration should be given to safety precautions for high-power testing due to this fact. The explosive nature of the test specimen also brings about special concern relating to safety in the laboratory. All the requirements of 5.1 should also be considered.

7.3.1 Use of Signal-Gathering Equipment

See Section 1 (8).

7.3.2 Use of Personnel-Protective Equipment

1) Eye and Face Protection
   a) Protective eye and face equipment should be worn by all personnel conducting or observing a high-power test where there is a reasonable probability that eye or face injury can be prevented by such equipment.

      NOTE — Typical eye and face hazards present in high-power test areas include intense light (including ultraviolet), sparks, and molten metal.
   b) Safety glasses containing absorptive lenses should be worn by all personnel observing a high-power test even when electric arcing is not expected. Lenses should be impact-resistant and have shade numbers consistent with the ambient illumination level of the work area but yet capable of providing protection against hazardous radiation due to any inadvertent electric arcing.
   c) whenever electric arcs are to be directly observed, safety glasses containing filter lenses should be worn by all personnel observing the electric arc test.
2) Head Protection
   a) All personnel conducting or observing a high-power test in areas where there is a possible danger of head injury from impact, failing or flying objects, or electrical shock and burns should be protected by protective helmets.
   b) Helmets for the head protection of personnel exposed to high-voltage electrical shock and bums should meet the specifications such as contained in ANSI Z89.1-1981 [3].
3) Noise Exposure. When personnel are subjected to high sound levels, suitable controls should be used to reduce these levels, or the duration of exposure to them (maximum levels are specified by OSHA in the United States and other authorities in other countries). If such controls are not feasible, ear-protective devices should be provided and used. Plain cottonbatting is not an acceptable protective device.
4) Other Protective Equipment
   a) Protective face-and-body shields or safety barriers should be used by all personnel conducting or observing a high-power test where there is a possibility of injury from flying material, solid, liquid, or gas, resulting from machines, test equipment, specimens, or operations associated with the test.

   - b) Whenever hazardous substances such as dust, fumes, mist, vapors, or gases exist or are produced in the course of high-power test work, appropriate approved respiratory protective devices should be worn by personnel present in the test area.
5) Personnel-protective equipment recommended herein should be in conformance with National Concensus Standards or regulations, or both. Some sources of concensus standards and regulations are referenced in Appendix B.

7.3.3 Special Equipment

1) Test Cell
   - a) A special test cell should be used in which to place the test specimen during the test because of the explosive and hazardous nature of high-power testing.
   - b) The test cell should be constructed to dissipate the energy of the worst case explosion, fire, or arc possible.
2) Fire Protection
   - a) Suitable fire protection should be provided to ensure the safety of all personnel and to lessen damage to equipment.
   - b) All fire-protection equipment should meet appropriate requirements. (See Appendix B for sources of regulations.)

8. Equipment Design

8.1 General

This section specifies the requirements for features to be incorporated in the design of portable, mobile, and permanently installed test equipment used in high-voltage measurements on power systems and apparatus.

8.2 Grounding

8.2.1 Ground Connection

The ground connection point should be clearly marked. The manufacturer of the equipment should specify the requirements for the ground connection. This should be indicated either by markings on the equipment or by a prominent notice in the instruction material supplied with the equipment. In specifying the type of ground connection, the manufacturer should consider the maximum current that can occur under worst-case conditions (either of fault or impulse) and ensure that the operator is protected from local-voltage elevation of the accessible conductive parts due to voltage drop in the ground connection.

NOTE — In general the current rating of the ground lead should exceed the current rating of the high-voltage lead and should also be mechanically suitable for the application. See Section 1(1)-(8). The use of protective equipment such as rubber gloves and mats may be included in this consideration provided that this fact is made obvious to the user.

8.2.2 Conductive Parts

All conductive parts accessible to the operator during the time that the equipment is operating at high voltage should be maintained at ground potential.

NOTE — This requirement should not apply to portions of the equipment intended to be isolated from the operator by suitable barriers as indicated in 5.1 and 5.3.

8.2.3 Grounded Shield

A grounded shield of sufficient conductance to protect the operator from internal voltage sources should be interposed between the operator and all high-voltage circuits where controls have to be manipulated while the equipment is operating at high voltage. All such controls which are actuated by a mechanism penetrating the shield should have the portion of the mechanism that is penetrating the shield made of highly conductive material directly connected to ground. The shield should have no openings which will allow the entry of a standard finger (for example, as specified in ANSI C39.5-1974, [2] and IEC 348 [5].)

8.2.4 Grounding Through Power Cord

Normal good practice requires the use of a grounding conductor in the power cord to connect the equipment to a ground connection in the power receptacle.

It should be noted that in some circumstances this practice can cause a hazard to personnel or prevent satisfactory measurements. If these conditions exist, the use of the grounding conductor is not mandatory. An equivalent safety ground should be provided and clear indication should be given of this circumstance both on the equipment and in the instruction material.

Equipment not intended for use with a third wire ground must have this fact indicated with markings on the instrument and in the instructions.

8.2.5 Safety Grounds

Where internal safety grounding is provided it should be possible to verify that it has operated correctly by visual inspection. One acceptable means is to provide a suitable window.

8.3 Design Features

8.3.1

The equipment should be mechanically stable on a level, smooth surface. Auxiliary means of stabilizing the structure, when required, should be specified by the manufacturer of the equipment. (see 8.3.7).

8.3.2

Means used for controlling the magnitude of high voltage used for a test may be equipped with a zero start circuit. This circuit is to ensure that when the high voltage is switched off it cannot be switched on again until the voltage control is reduced to zero.

8.3.3

All pressure vessels incorporated in high-voltage test equipment should conform to the ASME Boiler and Pressure Vessel Code, Section VIII, 1971 - Pressure Vessels Division 1, [4].

8.3.4

All high-voltage generating equipment should have a single obvious control to switch the equipment off under emergency conditions.

8.3.5

All high-voltage generating equipment should have an indicator which signals that the high-voltage output is enabled.

8.3.6

All high-voltage generating equipment should have provisions for external connections (interlock) which, when open, cause the high-voltage source to be switched off. These connections may be used for external safety interlocks in barriers or for a foot- or hand-operated safety switch.

8.3.7

The instruction material supplied with the equipment should indicate special conditions placed on the equipment by the designer concerning its use in various circumstances such as rain, high humidity, temperature extremes, high altitude, wind, etc.

8.4 Warnings and Safety Instructions

All equipment intended to generate or be directly connected to high voltage should carry a prominent warning of high voltage or be located within an enclosure that is so labeled.

8.5 Failure Analysis

8.5.1

The design of any piece of high-voltage test equipment should include a failure analysis to determine if the failure of any part of the circuit or the specimen to which it is connected will create a hazardous situation for the operator. The major failure shall be construed to include the probability of failure of items that would be overstressed as the result of the major failure. The analysis may be limited to the effect of one major failure at a time, provided that the major failure is obvious to the operator.

8.5.2

Where necessary the designer should specify limitations in the case of the equipment where safety will be affected by the application. This may include, but should not be limited to:

1) The maximum permissible short-circuit current of any high-voltage power source, not supplied with the equipment, to which the equipment may be connected. This may also include specification of protective devices used with such an external power source.
2) The maximum capacitance of specimen to which the equipment may be connected.
   NOTE — This rating may be changed by the user by adding auxiliary equipment; for example. supplementary discharge devices for dc test equipment.
3) The use of any special protective devices or clothing necessary for safe use of the equipment.

These limitations shall be clearly and prominently displayed in the instructions. Where appropriate they shall be marked on the instrument control panel or in another clearly visible position.

8.6 Equipment Mounted in Vans or Trailers

8.6.1

Equipment mounted in vans or trailers should be arranged so that the operators have an unobstructed line of exit in the event of a serious failure.

8.6.2

The layout of the van or trailer should be such that the operator has a satisfactory field of view from the control position. Where possible this view should include the test connections of the equipment and, where applicable, the specimen, observers, safety supervisor, etc.

8.6.3

The van or trailer should be grounded so that the chassis of the vehicle cannot be elevated to hazardous voltage under conditions of equipment or specimen failure. The safety ground of the equipment should be connected to the chassis of the van or trailer.

A. Typical Interlock Systems

(Informative)

(These Appendixes are not a part of IEEE Std 510-1983, IEEE Recommended Practices for Safety in High-Voltage and High-Power Testing.)

A.1 General

To guard against electrical hazards, test areas are enclosed by grounded metal fences with gates for passage of personnel and equipment. These gates should be interlocked with the high-voltage generating equipment to deny access to the area while tests are in progress. Some typical interlock schemes are described in this Appendix. Additional information is available in Rohlfs, A.F., and Brownlees, T., Safety in High-Voltage Testing. AIEE *Transactions on Power Apparatus and Systems*, PAS 73, Part IIIA, pp 473-477.

A.1.1

At approximately waist height, 115 V 2-conductor cables equipped with plug and socket connectors are attached to each gate and the adjacent fence. This system of connectors is arranged to form a series set of contacts to be used in ther interlock circuit of the high-voltage generating equipment (see 8.3.6). Opening any one of the contacts interrupts the input power to the high-voltage generating equipment either directly or indirectly by means of safety relays.

A.1.2

The interlock system governs the safe operation of a test area and it is of the utmost importance that it does not cause the wrong operation of the safety devices.

A.1.2.1

To prevent a ground fault from bypassing the interlock, a 2-wire grounded system is recommended. The two wires should be run side-by-side through all plugs, conduits, etc, and should enter and leave each gate in a different conduit. Short circuits or ground faults should cause fuses to blow, making the system fail-safe.

A.1.2.2

When the interlock system is designed to operate safety relays it may be desirable to use a redundant relay system to reduce the probability of malfunction of these devices (see A.3.3).

A.1.2.3

Should any indication of malfunction in the interlock system occur, such as blown fuses or signal lights operating out of proper sequence, testing should stop immediately and not resume until the problem has been identified and resolved.

A.2 Interlocks for Low-Power Systems

When only a small amount of test power is required it may be taken directly through the interlock system. In this case an interlock circuit within the test equipment itself is not required. An example of such a system is shown in Fig A.1.

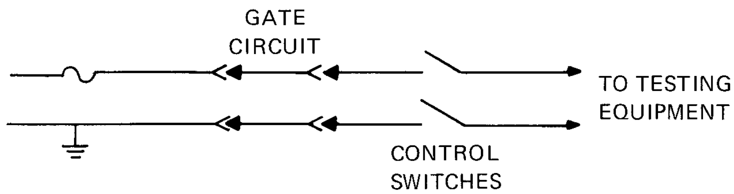

Figure A.1—Low-Power Interlock System

A.3 Interlock Systems Using Contactors

When moderate to heavy test power is required it is more practical to have the interlock system operate contactors in the control power or the test power circuit, or both, of the high-voltage generating equipment. Means are normally provided in high-voltage test equipment to accomplish this.

A.3.1

A typical system consists of an open set of contacts in series with the switch which energizes the contactor supplying power to the high-voltage generating equipment. The contactor cannot be closed until this set of contacts is closed by the interlock system. Conversely, if the interlock is interrupted while testing is in progress, the contactor will open removing power to the generating equipment.

A.3.2

A more sophisticated interlock scheme is shown in Fig A2. This illustrates the use of redundancy to reduce the probability of an interlock system malfunction. A pair of relays are energized when the interlock circuit is closed. Contacts on these relays are connected in series to provide control power. A second set of contacts is connected in parallel to provide status signal power. The same redundancy is used for the power contactors.

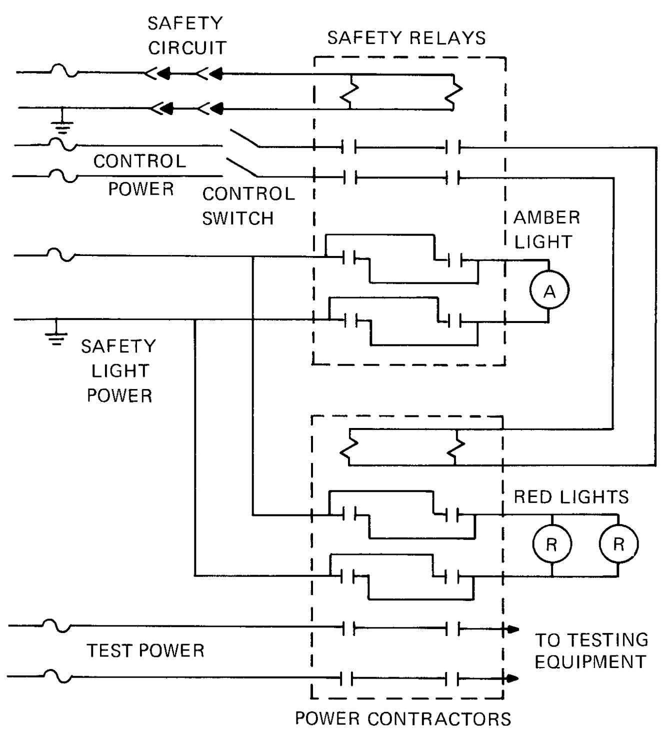

Figure A.2—Interlock Circuit Using Contactors and Relays for Testing Equipment with Moderate Power Requirements

A.3.3

Interlock systems may also be designed to use locks and keys. Such systems employ special locks which hold a key captive until the locking procedure is completed. The key can then be removed and used in a key-operated switch to the control system. Another safety scheme uses a key-operated switch which activates the control circuit and which the operator can remove and take with him when he enters the test area. This provides assurance that the system cannot be turned on while he is working in the test area.

A.3.4

Even the best interlock system should be considered to be only a back-up safety feature. An interlock should not be regarded as a substitute for adequate safety rules and proper operator vigilance.

B. Sources of National Consensus Standards and Regulations

(Informative)

National Consensus standards or OSHA regulations governing methods or devices to which reference is made in this standard are listed below.

In North America:

(ANSI) American National Standards Institute, Inc, 1430 Broadway, New York, NY 10018.

(ASTM) American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

(CSA) Canadian Standards Association, 178 Rexdale Boulevard, Rexdale, Ontario M9W 1R3, Canada.

(FM) Factory Mutual System, 1151 Boston-Providence Turnpike, Norwood, MA 02062

(IEEE) The Institute of Electrical and Electronics Engineers, Inc, 345 East 47th Street, New York, NY 10017.

(NFPA) National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

(OSHA) Occupational Safety and Health Administration, United States Department of Labor, Washington, DC (and regional offices).

(UL) Underwriters' Laboratories, Inc, 1285 Wait Whitman Boulevard, Melville, NY 11746.

In Europe:

(AFNOR) Association Francois de Normalisation, Tour Europe, Cedex 7, 92080 Paris - La Defense, France.

(BSI) British Standard Institution, 2 Park Street, London, W1A 2BS, England.

(CIGRÉ) International Conference on Large High-Voltage Systems, 112 Boulevard Haussmann, 75008 Paris, France.

(DNA) Deutschen Normenausschuess, 4-7 Burggrafenstrasse, 1 Berlin 30, Federal Republic of Germany.

(IBN) Institut Belge de Normalisation, Av de la Braborconne 29, B-1040 Brussels 4, Belgium.

(IEC) International Electrotechnicàl Commission, 1 Rue de Varembé, Genève, Switzerland.

(NNI) Néderlands Normalisatie Institute, Polakweg 4, Rijsweg (FN) - 2106, Netherlands.

(SNV) Association Suisse de Normalization, Kirchenweg 4, 8032 Zurich, Switzerland.

UNI) Enti Nazionale Italiani de Unificazione, Piazzo Armando Diaz 2, I 20123 Milano, Italy.

(VDE) Verbandes Deutscher Elektrotechniker, VDE-Verlag Gmbh, Bismarckstrasse 33 D-1000 Berlin 12, Federal Republic of Germany.