Electrical Safety ORC Review Guidelines for Experimental Installations

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Overview:
During these last couple of years, when reviewing the electrical aspects of experimental installations, particularly but not exclusively in the MTest area, several areas of concern seem to arise repeatedly. This document describes these common problems. It is intended to support but not to replace, revise or obfuscate the fundamental rules for the electrical safety applicable at Fermilab. Of course, sometimes an installation or piece of equipment requires special considerations due to operational requirements and that is why these are guidelines, not a list of inflexible rules. Keep in mind though; there are some fundamental rules with regards to electrical safety that must be adhered to. Also, I review the installation starting from the building's wall outlet or wiring. If special building wiring or modification is required, this will entail additional reviews and requirements.

The (Operational Readiness Clearance) review is a complete review of all aspects of an experimenters'/ users' installation of which the electrical components are just a part. Advisory reviews can be requested for any setup, no matter how complex, if there are any questions about safe operation and what should be done to ensure its safe operation, both for the knowledgeable persons and for persons who are not directly responsible for a setup's design or operation. Remember: if in doubt, **please ask!!**

Reference material used for the electrical safety review criteria:
The primary sources for these fundamental rules for the electrical safety of electrical installations at Fermilab are listed below:

- Electrical Design Standards for Electronics to be used in Experiment Apparatus at Fermilab, http://esh-docdb.fnal.gov/cgi-bin/ShowDocument?docid=2781
- Fermilab ES&H Manual Chapter 9000 Series, Fermilab Electrical Safety Program, http://esh.fnal.gov/xms/ESHQ-Manuals/FESHM

Commonly arising areas of concern during the electrical part of the ORC review:

1. Electrical Safety Grounds (Electrocution Hazard)
If AC line power (240/120 VAC) is used, any exposed metal on the equipment or metal where this equipment is sitting on or mounted to, must be tied (electrically bonded) to that AC power's safety ground. In the event of a power line fault to this metal, the current protection device for the equipment or wall panel breaker will fail or trip, respectively. The idea here is for a fault to not charge up any exposed metal to the AC power line's potential. For most installations, this requirement is satisfied by the use of the standard 3-prong AC plug and receptacle. For certain pieces of equipment or installations that do not use a 3-prong plug or when the grounding is not readily apparent, then the implementation of the safety grounds will need to be verified and/or additional connections or wiring may be necessary.

2. Current Protection for both AC and DC Powered Installations (Fire/Smoke Hazard)

All powered electrical equipment and conductors carrying that power to the equipment, needs to have current protection. This protection can be in the form of a current protection device (such as a fuse or circuit breaker). In the case of DC power coming from a power supply without fuse protection, the power supply must be current-limited so that no part of the installation can get current in excess of its rated capacity. In addition, this limiting ability of the power supply should not be easily changed by inadvertent contact with the power supply's controls (such as bumping a max current control knob). Otherwise, a fuse will be required at or near the source of the power. Always provide current protection if the current available, not just the normal operational current, exceeds the current capacity of the equipment or its conductors that supply that current. Current protection should be provided by devices designed for current protection. Do not use or depend on low-current rated components (such as an undersized resistor) to provide disconnection or "open up" in the event of an over-current condition. Most AC powered equipment, with very rare exceptions, should be fused protected. And finally, ribbon cable should be avoided as a power cable unless the maximum current available (fused or not) does not exceed the current capacity of a single ribbon cable conductor. Do not parallel ribbon-cable conductors (or other wire conductors for that matter) in order to deliver more current!

3. Custom-built Equipment

A majority of the installations usually involve the use of equipment designed and built by the experimenter or user, or by the institution to which they are affiliated. The question arises: Does this equipment need a special review prior to installation? The answer is yes. In particular, I will look at it and see if 1) it is properly grounded 2) the current protection for the incoming power (AC or DC) is sufficient 3) there are exposed high voltage or high current terminals or conductors. If I have not previously examined the equipment and or have not received sufficient wiring documentation, then I will need to examine it (open it up) during the review. Most times, this examination of custom-built equipment is done at the same time as the review of the installation. However, it is a good idea to request a preliminary or advisory review of the equipment prior to the ORC review. Commercially available equipment normally does not need to be separately reviewed.

A note of caution: Just because a piece of equipment is commercially produced, it does not mean that its use, in a test or experimental setup, is intrinsically safe. The same is true for combinations of “standard equipment”. For example, a standard, commercially produced house key, when inserted into a standard, commercially produced wall outlet is not necessarily safe. Therefore, the use of commercially produced equipment within a test installation or setup, will need to be reviewed during an ORC review. The internal workings of the commercial equipment are usually not reviewed however.

4. High Voltage Usage and Cabling

Almost all of the installations reviewed at MTest involved the use of high (meaning, over 50V) voltage. There is such a wide variety of different applications and implementations that to describe definitively what is and what is not allowed would take several pages. Therefore, I will just include a few things to consider (most of these are found in the Fermilab's ES&H Electrical Safety Manual, Chapter 9150):

1) Use the standard red-jacketed coaxial cables whenever possible along with the proper SHV coaxial connectors. If at all possible, avoid using standard BNC connectors (even though most are rated for 600 volts) to avoid confusion with other low-voltage BNC connectors. As a guide, do not use the standard BNC for voltages above 50V. (There is a judgment call when voltages below 120, such as the case for some DC power requirements are used with BNC connectors). In any case, make sure the connector used is rated for the voltage used. I will ask.

2) If the HV cables, other than the obvious power cords, used cannot be red and the connectors used are other than the SHV coaxial connectors, then the cables must be labeled at each end of the cable as HV. Also, if the corresponding bulkhead connector is not the standard SHV connector, then a label, indicating

this connector is used for HV, must be placed near this connector. Use the red/black/white colored caution labels (available at the Fermilab's stockroom) for voltages above 50 volts.

3) All HV conductors including the center conductor in a coax cable or a wire need to be protected by a continuously grounded metal surrounding such as the shield in a coax 4 cable or a metal box around a wire even if it is insulated. Also, the metal tables or stands on which the equipment is placed needs to be grounded to prevent the metal from being charged up to the HV potential in the case of a short between the conductor and its metal surroundings.

4) The maximum available current for the HV (unless operational requirements dictate otherwise) should be limited to <10 milliamps. If not, and reasonable by the circumstances of the installation, personal interlocks or some other personal protection procedures may be required. Again, special considerations for operation will be given when power supplies that operate above 50 volts are required and these will be decided on a case-by-case basis. Most HV usage at the MTBF uses the building's central HV distribution patch panel so for the most part, this current limit will not be a concern.

5) If a piece of equipment, including a module within a crate, uses a voltage above 50 volts, a caution label must be place visibly, indicating the presence of high voltage.

5. AC Power Cords, Power Strips, and Extension Cords

Since most installations are temporary (a few weeks or less), the use of extension cords to get AC power to a piece of equipment or to a rack power strip is normally allowed. Make sure that any mating connection is off the floor, or at a minimum, not subject to damage or pulling. It is a good idea to secure this connection with a tie-wrap or electrical tape. Whenever possible, plug the equipment or rack power strip directly into a wall outlet. "Daisy chained" connections of two or more power strips or extension cords are prohibited. Special AC power requirements, such as 240 VAC single-phase or 208 VAC three-phase, will be reviewed on a case-by-case basis.

6. Equipment Placement and Mounting (Falling Hazards)

Frequently, bench power supplies, oscilloscopes, or other pieces of equipment are placed sitting on a ledge, table, top of a rack, etc. Always place the equipment so it is firmly resting on a flat surface. For heights above head level, the equipment should be secured so that the pulling of a cord or cable, or the sudden movement of the flat surface, will not bring problems onto someone's head. Note also any tools or screws/hardware left on surfaces near equipment. You do not want to have something fall into a piece of equipment, especially if it is energized, and have it damage the equipment or cause a short. The resulting delays can be most frustrating.

7. Cable Strain Relief and Dress (Tripping and "Clothes-lining" Hazards)

Quite frequently, I notice cables and power cords massed together within racks or on the floor. Usually these cable masses and bundles present tripping hazards in and around equipment where people traffic is prevalent. Also, cables strung along upper supports are hung at or below head level, requiring people to duck and stoop. This is not to mention the tightness and angle of the cables with respect to its connectors. The advice here is simple: Run cables to avoid people traffic areas or to minimize trip hazards. Provide enough slack in the cables so that the connectors are not stressed which can damage the outer protective jackets. This is especially true for power cords. Tie-wrap the cables to "dress them down" so that inadvertently pulling on the cable will not damage the cable nor pull on the equipment to which that the cable is connected. Protect the power cords and keep them out of "pinch areas" that can damage the cords' protective jacket or conductors. Do not block easy egress from a working area.

8. DC Power Delivered by Coaxial Cables and Connectors

Sometimes coaxial cables, such as RG58 and RG174 cables, are used along with BNC type adaptors to deliver power to equipment. If possible, this should be avoided. Even if the voltages are below 50 volts, hazards exist from the potential for confusing a power cable and a signal cable. If power is used on a coaxial cable, this cable should be labeled at both ends of the cable to minimize this confusion and the potential for an unintentional smoke test. Also, keep in mind that the weak link as far as current capacity is the coaxial connector. LEMO or K-Lock type connector's max current ratings are usually 1.5 amps. The BNC style connectors are rated at 5 amps. However, these can change somewhat depending on the manufacturer. If the current requirement is around 4 amps or more, it is advisable to use a different connector. If the power is to be above 50 volts and at more than 10 milliamps (beginning point of adverse biological effects for DC currents) then more care must be taken to minimize the chance for personnel to inadvertently touch an energized conductor or contact. These actions may involve protective covers, more caution labeling, locking doors or covers, and up to and including personal interlock protection. It is always a good idea to supply any information with respect to the presence of these operating conditions to the reviewer prior to conducting the ORC review. This will save time in case protective or corrective measures need to be taken.

9. Rack Protection

As a norm, we do not require rack protection with interlocks for installations. These are at the discretion of the users and the requirements (or cost) of their equipment. If desired, we do have available, upon request with sufficient time to produce them, some rack-mounted units that provide smoke interlocks for AC power. In some situations, rack smoke detection and interlocks will be required. Some situations are, but not limited to: 1) large rack builds with lots of power dissipation, 2) use of very expensive or irreplaceable equipment should such equipment be fail, 3) Use of flammable materials near electrical equipment that can serve as an ignition source (high current densities or high voltage ; spark generation), 4) installations underground. As far as MTest is concerned, rack protection is not normally required. As always, ask the Fermilab's site supervisor or liaison if you are not sure.

Summary checklist: The following is a checklist of the above points of discussion:

1. **Safety Grounds:** Is the equipment using AC power? If so, is it properly safety grounded?

2. **Current Protection:** Are all of the power conductors properly sized for the maximum current available and not just sized for operational current? Will a short in any of these power cords/wires/cables blow the fuse or will the conductor overheat?

3. **Custom-built Equipment:** Is there custom-built equipment to be used? If so, I will at a minimum need to examine it for proper safety grounding and current protection.

4. **High Voltage Usage:** Does the equipment require a high voltage? If so, does the implementation follow the above listed guidelines (in item number 4)?

5. **AC Power Cords and Strips:** Are there any AC power strips connected in series? If so, split them up. Do the power cords used show signs of damage? If so, replace or repair them. Secure and protect any extension cords' interconnections. Are any cords near a “pinch area” such as a rack door or near a rack’s roller?

6. **Equipment Placement and Mounting:** Is any equipment resting on a surface above head level? Will any equipment fall if slightly bumped or if a connected cable/cord is pulled?

7. **Cable Strain Relief and Dress:** Are the signal cables too tight or at an angle (with respect to its connector) where the protective jacket is being damaged. Are the cables dressed down? Are the power cords secured and protected? Are any power cords pulling on the power plug such that a portion of its contacts are visible? Are there any cables that people can trip over or that are blocking any access/exit path?

8. **Power on Coaxial Cables and Connectors:** If using power delivered by coaxial cables, are they properly labeled at both ends? Do the coaxial connectors used have the proper current rating for the available (not just the

operational) current? If the operational voltage is above 50 volts, are protective measures in place to prevent any inadvertent touch of an energized contact or conductor? If you are not sure if any protective measures are required, please ask.