Photo by Dennis Schroeder, NREL 58020

Preparing Solar Photovoltaic Systems Against Storms

Introduction

The Federal Emergency Management Agency (FEMA) and subject matter experts at the National Renewable Energy Laboratory (NREL) compiled a set of checklists to help Puerto Rico and other communities prepare for storms. Renewable energy and distributed energy systems have the potential to provide power to neighborhoods, residents, and certain facilities within a community, if those systems are designed to provide power during a grid disruption. The storm-hardening checklists provide storm preparation actions that can increase the chances that solar photovoltaic (PV) systems are available following a severe weather event.

The overall goal of these checklists is to increase the survivability of solar PV systems after a storm. Increasing survivability leads to more power available to users immediately after the storm. Larger-scale PV systems can be used for essential services such as regional health care centers, emergency shelters, and water and wastewater treatment plants. Smaller-scale systems can provide local services such as refrigeration, communications, or mobile phone charging. Cumulatively, operational post-storm PV systems reduce the grid demand, allowing more customers to be served with limited post-storm grid generation sources.

In early September 2017, Hurricane Irma passed north of Puerto Rico, bringing high sustained winds and leaving over 1 million residents without power. Two weeks later, Hurricane Maria hit Puerto Rico at Category 4 strength, further damaging the power grid. The damage to the island's infrastructure limited humanitarian relief efforts, as well as repairs to the power grid. Two weeks after the hurricanes, the conditions for many residents had not changed, with 95% of the gird nonoperational, 95% of cell service out, half of the population without potable water, and 11,000 people in shelters.

Motivation

In some cases, solar PV systems can offer advantages as resilient power sources in the aftermath of disasters, including hurricanes. PV systems can produce power close to the end user and can provide diurnal power during a grid outage. When paired with battery storage systems and islanding controls, these systems can provide power 24/7.

For PV systems to provide power, the system itself must survive the catastrophic event. While many PV systems in Puerto Rico did survive the 2017 hurricanes, several did not. Post event reports and site assessments indicate that much of the damage to PV systems could have been avoided by taking relatively simple pre-storm preventative measures. The pre-storm checklists were developed to help avoid or limit damage to a PV system and support local post-storm power. The pre-storm checklists provide owners and operators with guidance to perform a cursory inspection of their PV system.

Intended Audience

These checklists are intended for those who own or operate PV systems: utility ground-mounted systems, distributed ground-mounted systems, and distributed roof-mounted systems. The intended audience varies based on the type and size of the PV system. Distributed systems include smaller-scale systems, such as residential systems where the electricity is used at or near where is it produced.

We assume that utilities and independent power producers (IPPs) are employing trained and certified electrical workers and have access to replacement parts or components, advanced toolkits, and heavy equipment to manage their ground-mounted PV systems. Distributed system owners are assumed to have few to none of these resources. Therefore, the utility and IPP may be able to address most issues found during their checklist, whereas residential system owners will likely not be able to address these issues until after the storm by consulting a certified electrician.

> Solar PV systems produce high voltages that can cause electrical shocks, leading to injury or death. It is crucial that only trained and qualified electricians perform work on the electrical components of a PV system.

How These Checklists Can Help

Increasing the survivability of PV systems also has local safety benefits. During high wind conditions, PV systems can be subjected to wind loading forces that can cause structural damage at the PV system anchoring points. When mounted to a rooftop, these forces can cause cracks or holes in the building envelope, allowing rain into the structure. Indoor flooding can result, potentially triggering a cascade of safety issues, including electric shock hazards, loss of shelter space, loss of access to food and drinking water, and increased risk of hypothermia.

Additionally, improper tightening and/or failure of the anchoring hardware can cause the PV modules or other components to become aerial projectiles. This can pose a direct hazard to people or can cause further damage to building infrastructure or other property. Following the relatively simple items on the checklists can significantly help avoid these issues.

Major Components of a PV System

The following section lists the key components of a PV system, provides a brief description of component functions, and describes issues that may affect component survivability during a storm.

Solar Photovoltaic (PV) Modules

A unit made up of the solar cells that convert solar radiation to electricity. Typically, solar modules have a glass top sheet above the solar cells. The glass sheet is held in place with a metal (usually aluminum) frame around the outside of the module. Storm events can crack or break the glass on modules or detach the frames. Modules are also sometimes referred to as "panels."

PV Cable Connectors

The electrical attachments between two modules. These need to be firmly attached and secured underneath the panels. They can come loose if allowed to blow in storm winds and can also be damaged if flooded. The PV cable connectors join several PV modules together in "strings." Electricity flows through these strings, then through cables to the inverter, ultimately delivering electricity to your house, or the grid.

DC Cables

DC cables carry the power from the solar modules to the inverter. They begin at the junction box, or J-box, on the backside of the panel. These cables should be routed with metal clips or wire ties. They should not be pulled too tightly so as to wear down the wire coatings. They should also not be dangling loosely and able to blow around in winds. They might be exposed underneath the solar modules but should be routed in conduits from the modules to the inverter.

Wire Ties or Clips

The wires that carry power from the PV modules are typically routed underneath the modules and held in place with wire ties or clips. These devices can be plastic or metal and hold the wires in place and prevent them from dangling loosely. Wires hanging loosely can be blown around and damaged or detached in high winds. Wire ties can degrade over time and break (especially plastic wire ties). Check underneath the PV modules in your system to ensure all wires are secured with ties or metal clips. If any are missing or if wires are hanging loosely, secure wires with ties or clips. Specially designed metal wire clips are ideal, but plastic ties will suffice as a temporary solution to limit potential damage.

Conduit

Conduit refers to tubes that protect and route wires in a system. They protect wires from UV exposure or other external factors that may damage them and secure the wires in place. Conduits can become damaged or detached in storms. Check to see that conduit is securely attached to the roof, sealed, and that the wires inside are not exposed.

Inverter

The inverter converts the DC energy to the AC energy that household appliances and the larger electrical grid use. This is typically a box on the side or inside of a building. In some cases, PV modules each can have "microinverters" under each module instead. Inverters can be damaged through water ingress from flooding or driven rain, flying debris, or electrical faults in the system.

Disconnects and System Shutdown Switches

Also called AC/DC disconnects. These are switches that cut off power from the solar modules and prevent it from flowing to the electrical grid or into a building. If you notice damage or a vulnerability to storm damage or suspect an electrical issue, the safest course of action is to disconnect the system. Disconnecting may also limit the amount of damage a system suffers in a storm. Note: Shutdown and disconnect procedures vary between systems; if possible, consult the system installer for proper shutdown or disconnect protocol.

Grounding System

Typically, green insulated wires or bare copper wires that connect all metal components of the system (such as the aluminum frames around modules) and allow charge to flow safely away from the system if any metal components become charged (they shouldn't be under normal operating conditions, and the grounding system is a safety precaution). The grounding wires are often connected to a metal stake driven into the ground.

Racking

Racking refers to the structure between the PV modules and the roof. There are many different racking designs. A common design is a metal grid that is attached to the roof that holds the PV modules. For flat roofs, a common racking system uses plastic pods that are held in place by concrete blocks or are attached directly into the roof. For standing seam metal roofs, metal attachments often connect to a seam of the roof and either hold a larger racking assembly or hold the modules directly.

Regardless of the type, racking can deform, bend, break, or come loose. A close visual inspection can usually reveal damage suffered from previous stresses. Look for bent components or parts that aren't secured tightly to each other. Prior damage leaves the system more susceptible to more damage in future events.

Fasteners (also attachments, bolted joints)

Fasteners include all the bolts, nuts, washers, clamps, clips, and other approaches to structurally holding the PV system together. Some fasteners may hold the PV modules to the racking, some hold the racking components to each other, some may attach the system to a roof, and others are used to secure the electrical components of a system. Fasteners that hold modules can hold them from the top with a clamp or attach the underneath of the modules to the racking. There are typically four attachment points per module, though individual systems vary. In weather events such as those with high winds, fasteners can vibrate and loosen or even pull out of the components they are intended to hold together. A visual inspection can typically identify missing fasteners. Checking fasteners with a wrench can also indicate if they are loose.

When and How to Use Pre-storm Checklists

The items on these checklists are intended to be tasks that a system owner or operator can complete several days or more before a storm arrives. Large storms such as hurricanes are typically forecast sufficiently in advance to allow safe examination of a PV system before they hit. Do not attempt to complete the checklist items after storm elements begin affecting the site. The items on this list also represent good regular or annual maintenance checks and practices to reduce system vulnerability to unexpected weather events as well.

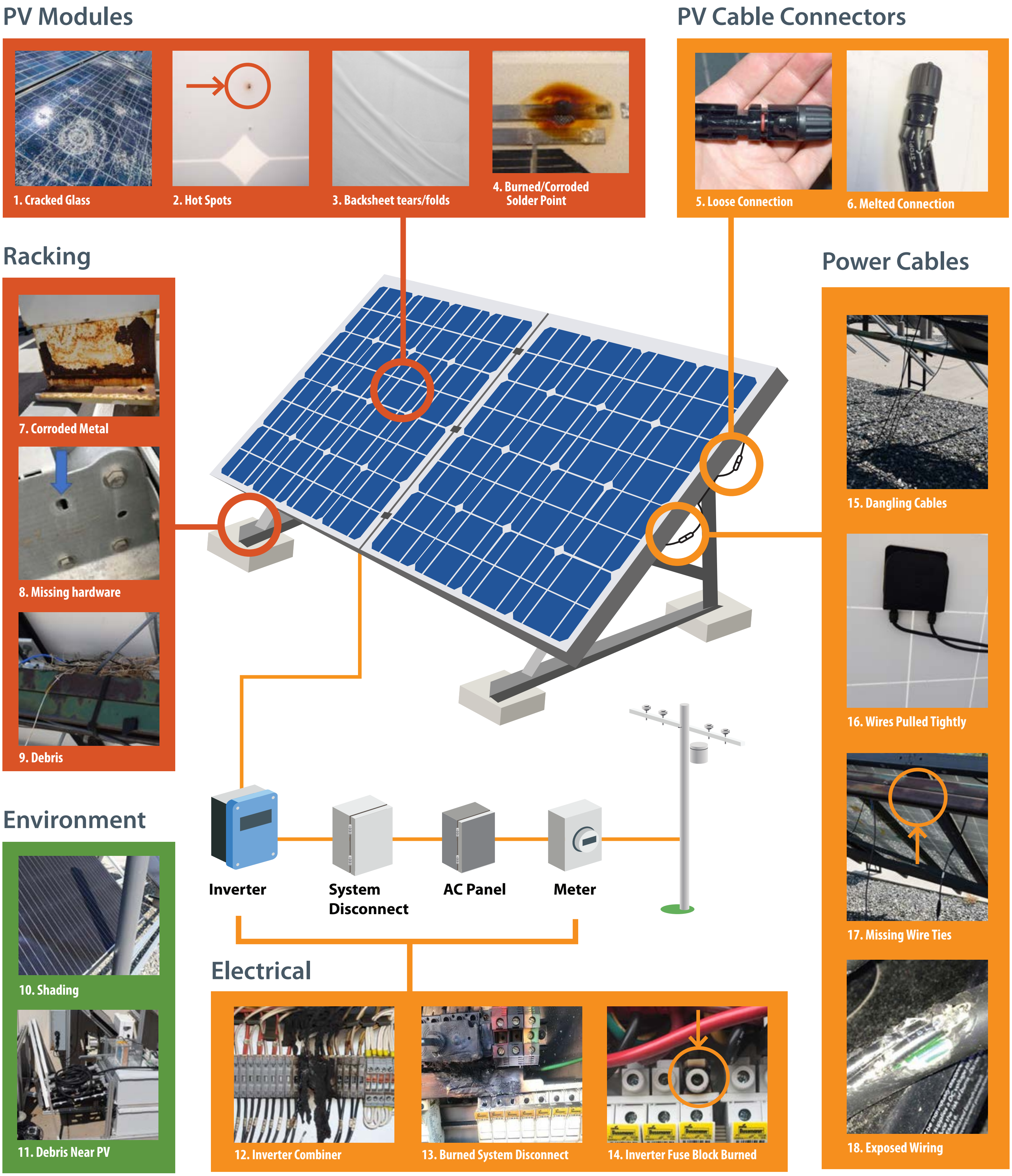
A pre-storm checklist has been created to meet the needs of each type of audience: utility ground-mounted systems, residential ground-mounted systems, and residential roof-mounted systems.

For ease of use, each pre-storm checklist is separated into three main topic areas: Site, Mechanical, and Electrical. The Site list focuses on the area and environment surrounding the PV system. The Mechanical list concentrates on the structural hardware that secures the PV system. The Electrical list follows the path of energy, from the PV modules to its connection to the grid or home.

Site Topic Area

The Site list is divided into two functional objectives: (1) Debris and (2) Flooding. The Debris list is focused on removing any debris, loose material, or other equipment that could move or become airborne during a storm and potentially damage the PV system, structures, or people. The Flooding list speaks to the potential for the PV system to become flooded during the storm. Preventing flooding is the primary goal through drainage and other engineering controls. If there is still a high risk of flooding, the system should be powered down during the storm and not energized again until checked by a certified electrician.

Photovoltaic System Damage



The images shown are merely examples and system components may look different.
Ask your installer if you are uncertain about any parts of your system.

Mechanical Topic Area

The Mechanical list is split into three subsystems: (1) Modules, (2) Fasteners, and (3) Racking. The Modules list inspects the PV module for structural damage or degradation from aging. The Fasteners list checks the hardware for structural integrity, any loose hardware that could worsen under high wind conditions, or any missing hardware that will leave the system susceptible to unnecessary damage in a storm. This includes the hardware to secure the PV module to the racking, a common problem area in high-wind conditions. The Racking list inspects the hardware that joins racking elements for structural integrity, corrosion, and loose or missing parts.

Electrical Topic Area

The Electrical list is broken into two subsystems: (1) Connectors, Wiring, and Supports, and (2) Waterproofing. The Connectors, Wiring, and Supports list starts at the junction box on the back side of each PV module and follows the wiring, connectors, and the cable management system to check for exposed wiring, faulty connectors, and loose or dangling wires. Each of these issues may initiate an electrical failure and result in potential electrical hazards. The Waterproofing list helps check any electrical enclosures to ensure they are water-tight and not likely to flood during the storm.

Resources to Learn More

Solar Photovoltaic Systems in Hurricanes and Other Severe Weather. U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, 2018. https://www.energy.gov/sites/prod/files/2018/08/f55/pv_severe_weather.pdf

Solar Photovoltaics in Severe Weather: Cost Considerations for Storm Hardening PV Systems for Resilience. National Renewable Energy Laboratory, 2020. https://www.nrel.gov/docs/fy20osti/75804.pdf

Solar Under Storm: Select Best Practices for Resilient Ground-Mount PV Systems with Hurricane Exposure. Rocky Mountain Institute, 2018. https://rmi.org/wp-content/uploads/2018/06/Islands_SolarUnderStorm_Report_digitalJune122018.pdf

Solar Under Storm Part II: Select Best Practices for Resilient Roof-Mount PV Systems with Hurricane Exposure. Rocky Mountain Institute, 2020. https://rmi.org/solar-under-storm-part-ii-designing-hurricane-resilient-pv-systems/

Wind Design for Solar Arrays. Structural Engineer's Association of California, 2017. https://www.seaoc.org/store/viewproduct.aspx?ID=10228815

Wind Design for Solar Photovoltaic Arrays on Flat Roofs. Structural Engineer's Association of California, 2012. https://www.seaoc.org/store/viewproduct.aspx?ID=9173712

Hurricanes Irma and Maria in Puerto Rico: Building Performance, Observations, Recommendations, and Technical Guidance. FEMA P-2020. October 2018. https://www.fema.gov/sites/default/files/2020-07/mat-report_hurricane-irma-maria-puerto-rico_2.pdf

Hurricanes Irma and Maria in the U.S. Virgin Islands: Building Performance, Observations, Recommendations, and Technical Guidance. FEMA P-2021. September 2018. https://www.fema.gov/sites/default/files/2020-07/mat-report_hurricane-irma-maria_virgin-islands.pdf

Planning, Procuring, And Managing Solar PV Systems For Long-Term Performance, FEMP, https://www.wbdg.org/continuing-education/femp-courses/fempodw077

PV System Owner's Guide to Identifying, Assessing, and Addressing Weather Vulnerabilities, Risks, and Impacts. U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, 2021. https://www.energy.gov/sites/default/files/2021-09/pv-system-owners-guide-to-weather-vulnerabilities.pdf

References

"Why Puerto Rico faces a monumental recovery effort." *USA Today*, September 26, 2017. https://web.archive.org/web/20210730222221/https://www.usatoday.com/story/news/nation/2017/09/26/why-puerto-rico-faces-monumental-recovery-effort/703515001/ (accessed April 2022)

"Wrap-up of damages in P.R. caused by Hurricane Irma." Casiano Communications, 2017 https://caribbeanbusiness.com/wrap-up-of-damages-in-p-r-caused-by-hurricane-irma/

"Nearly A Year After Maria, Puerto Rico Officials Claim Power Is Fully Restored." NPR, 2018. https://www.npr.org/2018/08/15/638739819/nearly-a-year-after-maria-puerto-rico-officials-claim-power-totally-restored

"Designing for the Wind: Using Dynamic Wind Analysis and Protective Stow Strategies to Lower Solar Tracker Lifetime Costs." NexTracker, A Flex Company, 2018. https://cdn2.hubspot.net/hubfs/1856748/nextracker_assets/pdfs/NEXT_whitepaper_092018.pdf

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Pre-Storm Solar PV Checklist: Distributed Ground-Mounted Systems

Site: Debris

- ❑ Clear site of all debris, material, and equipment no longer in use (see images 10-11), if possible; otherwise, tie down.
- ❑ Tie down or anchor HVAC and other in-use equipment.
- ❑ Cut back vegetation or tree branches that could cause damage to the system.

Site: Flooding

- ❑ Ensure flood control and drainage systems are functioning and clear of debris.

Mechanical: Module

- ❑ Check module framing to ensure structural integrity.
- ❑ Check module for damage (see images 1-4).
- ❑ Take photos to capture state of array before event.

Mechanical: Fasteners

- ❑ Perform a tightness check on the fasteners in the system and tighten, if possible.
- ❑ Check for any missing or corroded fasteners and replace, if possible.

Mechanical: Racking

- ❑ Check all hardware for corrosion, missing or damaged parts (see images 7-8), and replace, if possible.
- ❑ Remove any debris (see image 9).
- ❑ Perform a tightness check on the racking hardware and tighten, if possible.

Electrical: Connectors, Wiring, and Supports

- ❑ Before conducting any electrical adjustments or modifications, ensure all system AC/DC disconnects, fuses, switches, and circuit breakers are in the open position. Ensure all electrical work is performed by a qualified electrician.*
- ❑ Check J-box is securely attached to the module and is intact.*
- ❑ Check that PV cable connections are connected securely (see image 5), free of corrosion, and not damaged (see image 6).*
- ❑ Ensure all cable ties are in place (see image 17), holding cable securely to the module frames and racking. Cable should not be dangling or loose (see image 15) but should not be pulled taut (see image 16) or against metal surfaces that might wear out the sheathing in high winds or damage the connectors.* Replace damaged or worn materials with UV-resistant ties and wire clips/clamps (preferably metal and not plastic) on modules and rails, if possible.
- ❑ Check all system wiring from the modules to the inverter for exposed conductors (see image 18).*

Continued on next page

Pre-Storm Solar PV Checklist: Distributed Ground-Mounted Systems *continued*

- ❑ Inspect other cable connections for secure contact and corrosion.*
- ❑ If using conduit, check conduit to ensure it is not damaged and is continuous.*
- ❑ If using conduit, check conduit supports and ensure conduit is secured.
- ❑ Check enclosures for integrity, corrosion, and watertightness. This includes combiner boxes, inverter boxes, and battery storage enclosures.*
- ❑ Perform a tightness check on the structural mounting hardware for the enclosures and tighten, if possible.
- ❑ Check electrical connections in enclosures for corrosion, damaged or burned connections (see images 12-14), including all bolted power connectors.*
- ❑ Check grounding system for tightness of connections and visual continuity of system.*

Electrical: Waterproofing

- ❑ Check gasketing, conduit fittings, and seals on penetrations in electrical enclosures to prevent wind-driven rain; tighten and/or apply outdoor-rated sealant if possible.
- ❑ Ensure access panels to equipment are closed and latched, if possible.

Final Steps

- ❑ During the storm, it is recommended that the system be powered down and turn all disconnects into the "open" position.*

*Electrical caution should be taken.

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