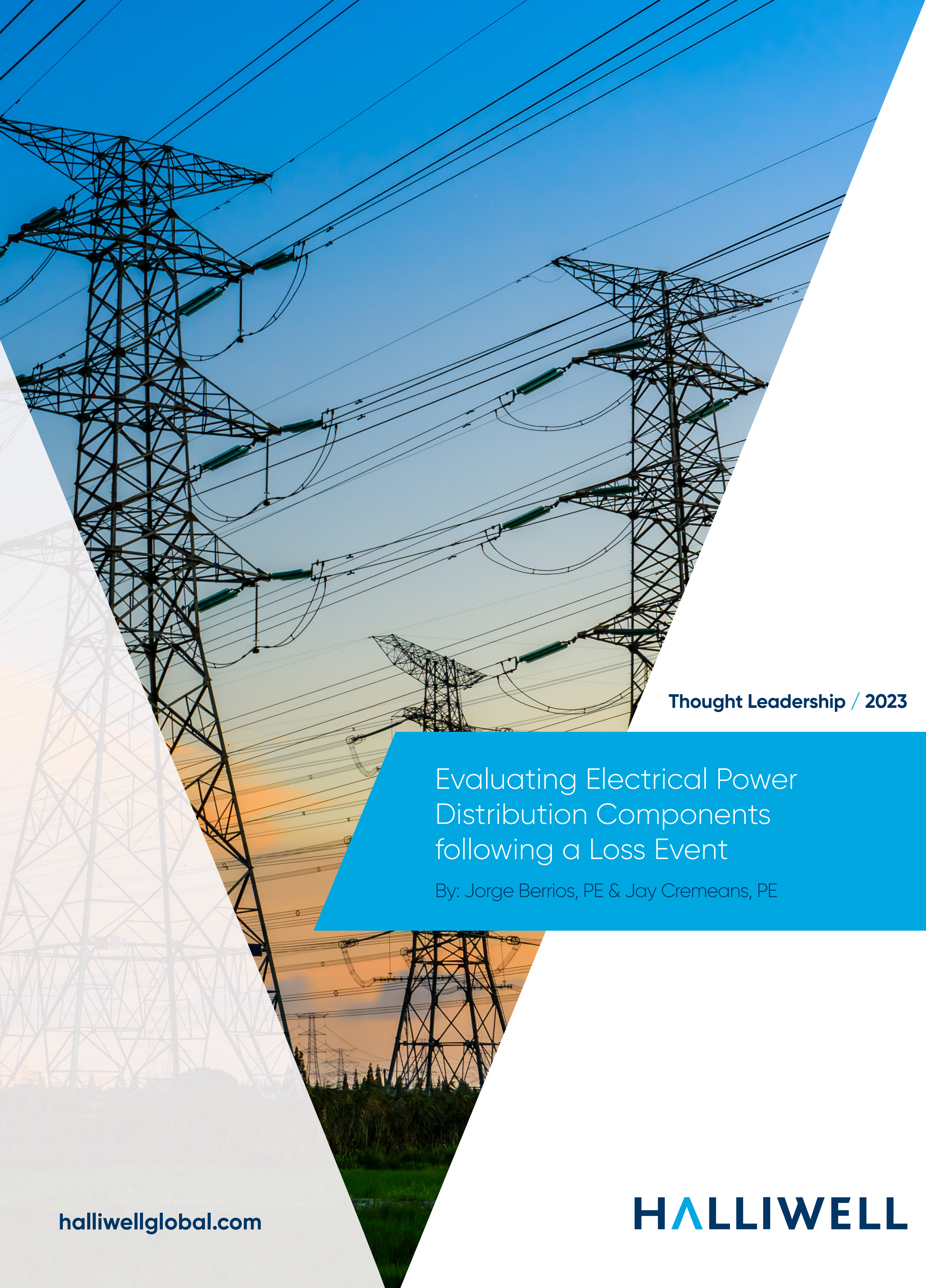

Thought Leadership / 2023

Evaluating Electrical Power Distribution Components following a Loss Event

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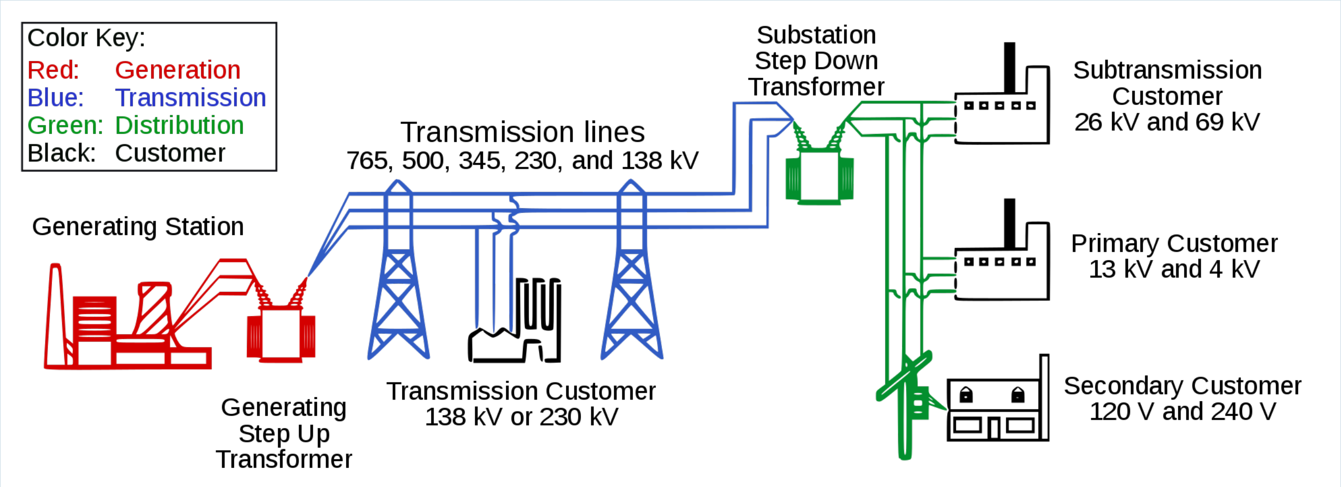
Have you ever seen news footage of the aftermath of a hurricane on a hospital or a factory? Or witnessed firsthand losing power in your building during a flood or thunderstorm? The Federal Emergency Management Authority (FEMA) indicates that the most immediate and significant impact during a disaster is loss of power. During adverse weather events, like hurricanes, typhoons, floods, tornados or snowstorms, transmission and distribution networks are often disrupted, and power cannot get to the end user. Water damage is especially difficult to recover from, particularly from coastal flooding due to corrosion caused by prolonged exposure to saltwater[1]. Interruption of power is not only an inconvenience to daily life, but it also has drastic effects on the economy's supply chain, emergency care, water, transportation, and telecommunications systems. Therefore, it's imperative to remediate quickly. But what is electrical power, how is it supplied, and what happens when supply is interrupted?

The US Environmental Protection Agency (EPA) defines the electricity grid as "a complex machine in which electricity is generated at centralized power plants and decentralized units and is transported through a system of substations, transformers, transmission lines and distribution lines that deliver the product to its end user, the consumer".[2] The US Department of Energy (US DOE) states that "America's economy, national security, and even the health and safety of our citizens depend on the reliable delivery of electricity" to over 140 million customers divided into three categories: residential (122 million customers; 37% electricity sales); commercial (17 million; 35% sales); and industrial (<1 million; 28% sales)[1] It would be safe to say that everyone in the US relies on electricity in some form.

While riding in the backseat as a child looking out the window on a long trip with your parents to a vacation destination, you may remember how it seemed like it took forever to get there and asking your parents the age-old question "Are we there yet?" seemingly every fifteen minutes in a daze as you whizzed by endless miles of transmission lines. As you gazed out the window of the car's backseat, you probably saw structures similar to the picture below.

Section of transmission lines



Simplified depiction of electrical power delivery to customers[5]

Those catenary curves of power lines affixed to the endless rows of towers are part of a massive energy infrastructure that spans the entire US. These transmission lines deliver electricity converted from conventional power generation plants, as well as renewable sources such as wind farms and solar arrays. The main characteristics that distinguish transmission lines from distribution lines are that they are operated at relatively higher voltages, transmit larger amounts of power over longer distances, and supply substations where voltage is transformed to a lower level for delivery to customers.

A simplified depiction of how power is delivered to end users is presented in the above graphic, showing the US energy grid generally subdivided into three main sections: Generation, Transmission, and Distribution. The US DOE notes that "the U.S. electric grid is an engineering marvel with more than 9,200 electric generating units having more than 1 million megawatts of generating capacity connected to more than 600,000 miles of transmission lines."[4] To put this total transmission line length in perspective, imagine laying each transmission line end to end and wrapping the combined length around the equator like a string. An equivalent length would encircle the earth 24.1 times!

Power moving through the transmission system must be reduced to lower voltage levels before it can be delivered to a factory, complex, business or residence. The voltage level is reduced, or "stepped down", via transformers and sent through distribution lines which are then connected to other electrical components, some of which will be described further in this piece.

In this article, we will focus on the distribution system elements, and review the common electrical components that exist within industrial and commercial facilities, as well as the common evaluation and testing methods used to ascertain the electrical integrity of impacted electrical components to restore the system to their pre-event condition following damage.

BASIC ELECTRICAL DEFINITIONS

The following common terms will aid in understanding the electrical components and evaluation and testing discussion that follows.

Voltage (V) – A measure of the difference in electric potential between two points in space, a material, or an electric circuit (measured in volts; abbreviated as "V").

Amperage (I) – The strength of an electric current (measured in amperes; abbreviated as "amps" or "A").

Resistance (R) – A measure of the opposition to current flow in an electrical circuit (measured in ohms; abbreviated as the Greek letter "omega" or "Ω").

Insulation Resistance (IR) – A measure of the resistance between two energized parts or conductors or the resistance between an energized part and ground potential (measured in ohms).

Power (VA) – The rate of energy transfer by an electric circuit per unit of time (measured in watts; abbreviated as "W"; or volt-amperes; abbreviated as "VA").

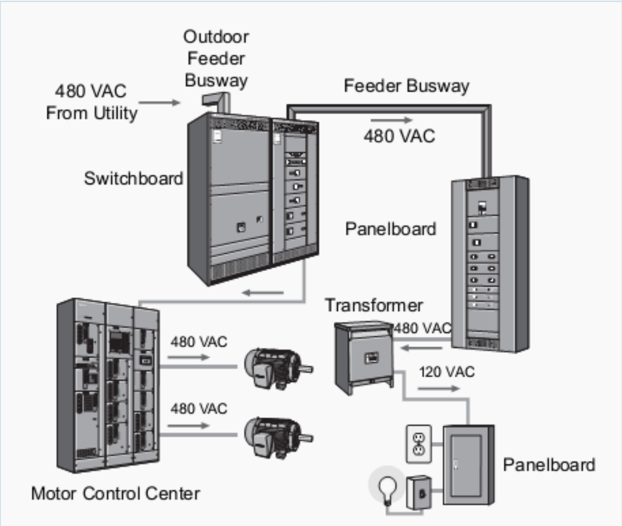
Power = Voltage x Amperage (units of watts or volt-amperes)

Energy – Electrical energy transfer by an electric circuit (measured in watt-hours).

Energy = Power x Time (units of watt-hours)

POWER SYSTEM OVERVIEW

Power distribution systems used in large commercial and industrial facilities can be very complex. Distribution of power to HVAC, lighting, and motor-driven machinery is typically delivered to the load through switchgear and/or switchboards, step-down transformers, motor control centers, and panelboards. The graphic below depicts a typical layout of power distribution components utilized to supply loads.



Typical power distribution[6]

SWITCHBOARDS AND SWITCHGEAR

Switchboards and switchgear are typically the facility's inlet point for power from the utility grid.

According to the National Electrical Code (NEC) Article 100, a switchboard is defined as "a large single panel, frame, or assembly of panels on which are mounted on the face, back, or both, switches, overcurrent, and other protective devices, buses, and usually instruments. These assemblies are generally accessible from the rear as well as from the front and are not intended to be installed in cabinets."[4] Switchboards are designed to Underwriter's Laboratories (UL) Standard 891, but also have contributing standards from UL 1066.

Switchboards are commonly found throughout telecommunication buildings, health care facilities, public offices, and other commercial and industrial facilities. A switchboard is divided into different adjoined and interconnected sections and usually contains a main section housing the incoming utility feeders, as well as the main service disconnect. In most instances, the switchboard has one or more distribution sections which are outfitted with overcurrent protective devices for downstream circuits feeding larger single point loads, motor control centers, and panelboards. The overcurrent protective devices can either be group mounted in a distribution section of the switchboard or compartmentalized with one device in each compartment. The method of compartmentalization is employed in consideration of maintenance and repair, among other needs specified by the facility. Where higher fault current withstand is required or where maintenance considerations come into play, compartmentalization with a draw-out drawer design is employed.

Overcurrent protective devices used on switchboards can be either fixed-mount or draw-out devices. The reason for this beefed-up connection method is to allow the breaker to handle higher short circuit currents (up to 200,000 amperes) in a fault scenario. UL 891 requires breakers to handle the fault currents up to their rating for three (3) electrical cycles (1/20th of a second). Switchboards are much larger than panelboards, rated between 1200 amperes and 5000 amperes with voltages up to 600 V, and ranging between 24 inches to four (4) feet deep and 90 inches high. Per UL 891, switchboards are typically configured for front access only and are floor-mounted with the rear section against the wall; however, they can also be configured to be front and rear accessible depending on the application.

By contrast, switchgear are larger versions of switchboards and are rated up to 38 kV and 6000 amperes. According to NEC Article 100, a switchgear is defined as "an assembly completely enclosed on all sides and top with sheet metal (except for ventilating openings and inspection windows) and containing primary power circuit switching, interrupting devices, or both, with buses and connections. Dielectric barriers separate the compartmented sections therein. The assembly may include control and auxiliary devices. Access to the interior of the enclosure is provided by doors, removable covers, or both."[7] Depending on size and configuration, Switchgear design standards are found throughout UL 1558, UL 1066, ANSI C37.13 and NEMA SG-3. Switchgear enclosures are typically designed for both front and rear access and require a larger footprint than switchboards.

In contrasting switchgear to switchboards, draw-out breakers are typically utilized in switchgear applications. The reason for this is not only to provide capability to withstand even higher short circuit conditions, but also in consideration of maintenance and troubleshooting. Switchgear draw-out breakers are rated to withstand short circuit conditions for up to 30 cycles (1/2 of a second). By contrast, panelboards and switchboards are only rated to withstand short circuits for a maximum of three (3) cycles (1/20th of a second). Further, draw-out breakers can be racked-out from the bus via utilization of a drawer design, removed for maintenance, and replaced with spare devices minimizing downtimes. Some current technologies include remote circuit breaker racking systems able to remove or insert draw-out breakers to prevent workers from becoming exposed to high arc flash incident energy levels. This is not the case with panelboards and switchboards incorporating fixed-mount devices.

Switchboards and switchgear[8]

BUSWAYS

As a substitute for traditional cabling throughout a facility, busways are commonly utilized. NEMA defines a busway as a prefabricated electrical distribution system consisting of bus bars in a protective enclosure, including straight lengths, fittings, devices and accessories. Busways interconnect panelboards, switchboards, and switchgear, among others. Busways can either be installed along the ceiling in a horizontal configuration or as vertical busway risers in penetrating the floors of a multistory building. Busway types include sandwich-style, non-segregated, and track.

Example of a horizontal busway installation along the ceiling[9]

Example of a vertical busway riser [10]

PANELBOARDS

Panelboards are electrical distribution components that share many of the same functions as switchboards but have several distinct differences that set them apart. The most apparent differences are that a panelboard typically mounts to the wall, they only allow front access, and operate at much lower amperages typically maxing out at 1,200 A.

In most applications, panelboards are rated for up to 600 volts. They have multiple purposes based on design and layout and are most often employed to feed lighting systems, HVAC loads, and other power circuits.

In accordance with NEC Article 100, a panelboard is defined as "a single panel or a group of panel units designed for assembly in the form of a single panel, including buses and automatic overcurrent devices; equipped with or without switches for the control of light, heat, or power circuits; designed to be placed in a cabinet or cutout box placed in or against a wall or partition; and accessible only from the front."[7] Panelboards are designed to UL Standard 67 with contributions from NEMA PB-1.

These panels are equipped with Overcurrent Protection Devices which protect branch circuit conductors from electrical damage due to overload or short circuit conditions. The branch circuit wiring supplies lights, air conditioners, receptacles, refrigerators, computers, and others.

In commercial and industrial applications, these panels typically supply branch circuits and are in turn supplied power by switchboard feeders. In applications where the voltage requires adjustment to match a load, a transformer is employed. Although panelboards are rated up to 600 V, typical sizes range from 225 Amperes up to 1200 Amperes at voltages that are, typically, 480/277 Volts or 208/120 Volts. Depending on the configuration of breakers installed therein, panelboards are rated to handle fault currents of up to 100,000 Amperes.

Panelboards[11]

TRANSFORMERS

In short, a transformer is "a device that transfers electric energy from one alternating-current circuit to one or more other circuits, either increasing (stepping up) or reducing (stepping down) the voltage."[12]

Dry-type transformer[13]

Oli-filled substation transformer[14]

In commercial and industrial applications, dry-type transformers are commonly found either wall or floor-mounted and located in electrical rooms.

These distribution transformers are typically utilized to provide a lower or higher voltage level to panelboards. In larger installations, oil-filled transformers are utilized and are sized to step down a transmission voltage (typically, 34.5kV or 13.8kV) to the voltage required by the facility (usually 480/277 Volts or 208/120 Volts).

MOTOR CONTROL CENTERS (MCCS)

Whenever motors are employed in a commercial or industrial application, the motor operation must be controlled. In the most basic scenario, motor starters consist of an on/off selector switch or pushbuttons, a contactor, indicator lights, fuses, and an overload relay. In more complex applications involving starting current and speed control for process applications, Soft Starters and Variable Frequency Drives (VFDs) are utilized.

In many cases throughout commercial and industrial sites, a large quantity of motors are needed. In these instances, a Motor Control Center (MCC) is utilized to allow operator control of the motors in a central location. Simply put, an MCC is a grouping of motor starters in a single enclosure. The MCC is fed power from a Switchboard or Switchgear and distributes the power to the various motor starter buckets contained within the MCC.

Example of an MCC

EVALUATION AND TESTING OF ELECTRICAL COMPONENTS

When components are impacted by water intrusion from an event, fire damage, electrical faults, lightning strikes, or age-based deterioration, an analysis is performed to determine the root cause of the failure and the feasibility of repair vs. replacement options. The National Equipment Manufacturers Association (NEMA) provides guidance in evaluating water (via GD-1) and fire/heat (via GD-2) damage. These documents are a summary of repairability or replacement options opined by the various participating members of the NEMA association. Both documents tabulate the categories of components for a quick guide in analysis. A sample excerpt of each is provided below.

Equipment	Replace equipment	May be reconditioned (contact the manufacturer)	Additional standards reference (if available)
ELECTRICAL DISTRIBUTION EQUIPMENT (refer to 4.1)			
Molded-case circuit breakers	X		
Low-voltage fuses	X		
Switches	X		NEMA KS 3-2010 *Guidelines for Inspection and Preventive Maintenance of Switches Used in Commercial and Industrial Applications*
Busway (Mylar wrapped bars)	X		NEMA BU 1.1-2000 *General Instructions for Handling, Installation, Operation, and Maintenance of Busway Rated 600 Volts or Less*, par. 3.4.4, 9.2.4.2
Busway (powder-coated bars)		X	
Panelboards		X	NEMA PB 1.1-2013 *General Instructions for Proper Installation, Operation, and Maintenance of Panelboards Rated 600 Volts or Less*, par. 10.3, 10.8, 10.8.3, 10.8.4, 10.9
Switchboards		X	NEMA PB 2.1-2013 *General Instructions for Proper Handling, Installation, Operation and Maintenance of Deadfront Distribution Switchboards Rated 600 Volts or Less*, par. 9.1, 9.8, 9.8.3, 9.8.4, 9.9
MOTOR CONTROL EQUIPMENT (refer to 4.2)			
Adjustable speed drives	X		
Components containing semiconductors and transistors	X		
Electronically controlled and solid-state contactors and starters	X		
Overload relays	X		
Manual and magnetic controllers		X	
Motor control centers (see 4.2.2)		X	

Excerpt from NEMA GD-1 – Electrical Equipment Replacement/Reconditioning Requirements[15]

Equipment	Replace equipment	Potential for reconditioning (contact the manufacturer)	Additional Standards reference (if available)
ELECTRICAL DISTRIBUTION EQUIPMENT (refer to 6.1)			
Molded-case circuit breakers	X		ANSI/NEMA AB 4-2017 *Guidelines for Inspection and Preventive Maintenance of Molded-Case Circuit Breakers Used in Commercial and Industrial Applications*
Low-voltage fuses	X		
Enclosed switches	X		NEMA KS 3-2010 *Guidelines for Inspection and Preventive Maintenance of Switches Used in Commercial and Industrial Applications*
Busway (Mylar-wrapped bars)	X		NEMA BU 1.1-2010 *General Instructions for Handling, Installation, Operation, and Maintenance of Busway Rated 600 V or Less*
Busway (powder-coated bars)	X		
Panelboards	X		NEMA PB 1.1-2013 *General Instructions for Proper Installation, Operation, and Maintenance of Panelboards Rated 600 Volts or Less*, par. 10.3, 10.7, 10.8, 10.8.3, 10.8.4, 10.9
Transfer switches	X		NEMA ICS 10 Part 1-2020 *Industrial Control and Systems, Part 1: Electromechanical AC Transfer Switch Equipment*
Switchboards		X	NEMA PB 2.1-2013 *General Instructions for Proper Handling, Installation, Operation, and Maintenance of Deadfront Distribution Switchboards Rated 600 Volts or Less*, par. 9.1, 9.7, 9.8, 9.8.3, 9.8.4, and 9.9, and 2020 NEC Section 4080.8
MOTOR CONTROL EQUIPMENT (refer to 6.2)			
Adjustable speed drives	X		
Components containing semiconductors and transistors	X		
Electronically controlled and solid state contactors and starters	X		
Overload relays	X		

Excerpt from NEMA GD-2 - Electrical Equipment Replacement/Reconditioning Requirements[16]

When it is determined that electrical testing can add valuable data in evaluating component health, the ANSI/NETA Maintenance Testing Specification (MTS) is employed. This comprehensive testing document serves to standardize the electrical testing of components across the industry. The MTS provides guidance for safety and precautions, division of responsibilities, instrument calibration, visual and mechanical checks, electrical testing, and reporting. Below is an excerpt of the testing derived from ANSI/NETA MTS 2023 for switchboards, switchgear, and panelboards.

7. INSPECTION AND TEST PROCEDURES

7.1 Switchgear and Switchboard Assemblies

A. Visual and Mechanical Inspection

1. Inspect physical, electrical, and mechanical condition.
2. Inspect anchorage, alignment, grounding, and required area clearances.
*3. Prior to cleaning the unit, perform as-found tests.
4. Clean the unit.
5. Verify that fuse and/or circuit breaker sizes and types correspond to drawings and coordination study as well as to the circuit breaker address for microprocessor-communication packages.
6. Verify that current and voltage transformer ratios correspond to drawings.
7. Verify that wiring connections are tight and that wiring is secure to prevent damage during routine operation of moving parts.
8. Inspect bolted electrical connections for high resistance using one or more of the following:
    1. Use of a low-resistance ohmmeter in accordance with Section 7.1.B.1.
    2. Verify tightness of accessible bolted electrical connections by calibrated torque-wrench method in accordance with manufacturer's published data or Table 100.12.
    3. Perform a thermographic survey in accordance with Section 9.
9. Confirm correct operation and sequencing of electrical and mechanical interlock systems.
    1. Attempt closure on locked-open devices. Attempt to open locked-closed devices.
    2. Make key exchange with all devices included in the interlock scheme as applicable.
10. Use appropriate lubrication on moving current-carrying parts and on moving and sliding surfaces.
11. Inspect insulators for evidence of physical damage or contaminated surfaces.
12. Verify correct barrier and shutter installation and operation.
13. Exercise all active components.
14. Inspect mechanical indicating devices for correct operation.

* Optional

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Excerpt of Visual and Mechanical Inspections from ANSI/NETA MTS 2023[17]

7. INSPECTION AND TEST PROCEDURES

7.1 Switchgear and Switchboard Assemblies *(continued)*

15. Verify that filters are in place, filters are clean and free from debris, and vents are clear
16. Perform visual and mechanical inspection of instrument transformers in accordance with Section 7.10.
17. Perform visual and mechanical inspection of surge arresters in accordance with Section 7.19.
18. Inspect control power transformers.
    1. Inspect for physical damage, cracked insulation, broken leads, tightness of connections, defective wiring, and overall general condition.
    2. Verify that primary and secondary fuse or circuit breaker ratings match drawings.
    3. Verify correct functioning of drawout disconnecting contacts, grounding contacts, and interlocks.
19. Perform as-left tests.

B. Electrical Tests

1. Perform resistance measurements through bolted electrical connections with a low-resistance ohmmeter in accordance with Section 7.1.A.8.1.
2. Perform insulation-resistance tests for one minute on each bus section, phase-to-phase and phase-to-ground. Apply voltage in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.1.
*3. Perform a dielectric withstand voltage test on each bus section, each phase-to-ground with phases not under test grounded, in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.2. The test voltage shall be applied for one minute. Refer to Section 7.1.3 before performing test.
*4. Perform insulation-resistance tests on control wiring with respect to ground. The applied potential shall be 500 volts dc for 300-volt rated cable and 1000 volts dc for 600-volt rated cable. Test duration shall be one minute. For units with solid-state components or control devices that cannot tolerate the applied voltage, follow manufacturer's recommendation.
5. Perform electrical tests on instrument transformers in accordance with Section 7.10.
6. Perform ground-resistance tests in accordance with Section 7.13.
7. Test metering devices in accordance with Section 7.11.
8. Control Power Transformers.

* Optional

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Excerpt of Electrical Tests from ANSI/NETA MTS 2023[17]

The first step in analyzing the electrical integrity of an electrical component, cable, or busway is the measure of insulation resistance. There are other tests prescribed by the MTS, but insulation resistance is the most frequently employed as an initial health gauge preceding a more thorough suite of electrical tests. Insulation resistance values vary depending on insulation makeup and is affected by moisture, age, and other outside factors, but a typical focus is to expect insulation resistance values in the millions or even billions of ohms. The higher the resistance, the greater the integrity of the insulation. Lower insulation resistance readings are a useful data set when analyzing component health, as they are indicative of insulation degradation. Other valuable investigation methods include bolted connection resistance measurements, oil sample analysis, thermographic surveys, turns ratio tests, online partial discharge tests, and several other analyses.

Electrical equipment exposed to contaminants can be extremely hazardous if reenergized without performing a proper evaluation and taking necessary actions. Reductions in the integrity of electrical equipment due to water, heat, and fire residue can affect the ability of the equipment to perform its intended function and can pose a safety hazard to personnel and property. Engaging a qualified expert to assess the extent of impact to electrical components is of utmost importance in the recovery efforts following a loss. Halliwell has decades of combined experience in these types of investigations.

While this article was intended to provide a brief overview of common electrical components that are typically encountered in an industrial or commercial setting, as well as their evaluation and testing after a loss, Halliwell is well-versed in all areas of electrical engineering evaluation including generating stations, transmission, distribution, and customer usage. We are at the forefront in providing engineering evaluation as part of the rapid response to events within the electrical market and provide expertise for all sections of the US energy grid. We provide solutions for traditional power generation modes as well as cutting edge technology involving solar PV arrays and wind turbines.

We hope you have enjoyed this article and found the content useful and informative. Please watch for future articles in this series as we dig deeper into the specifics of electrical components, their proper evaluation, and testing methods.

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