Assessing the Health of a Facility's Electrical Power Distribution System

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1.0 Abstract

An issue of vital concern in any business environment is the “health” of the electrical system infrastructures that work behind the scenes. Like any engineered system, electrical power distribution systems cannot be designed and constructed to operate 100% of the time indefinitely. Whether for a relatively new power system or for an older existing installation, an assessment of the system condition can mean the difference between an electrical power distribution system that operates as designed and intended and one that does not.

This paper gives the basic considerations that should be taken into account for assessments of the electrical power distribution systems within commercial or industrial facilities, including code compliance and grounding issues. The procedures for carrying out assessments are also outlined, as well as the concerns and issues to be aware of that could compromise performance and/or safety of a commercial or industrial facility. Charts are presented to show losses resulting from electrical equipment failures.

2.0 Why Perform an Assessment?

There are numerous reasons why it may become necessary to perform an assessment of the Power Distribution System (PDS) of a specific commercial and industrial facility or hospital. The most common reasons that PDS assessments are commissioned are usually associated with an event or events that occurred and caused the facility's engineering or operations staff concerns, problems, or stress. Some typical examples are listed below.

- Nuisance tripping of protective devices
- Evaluation of devices or equipment as protective relays or circuit breakers to determine functionality and reliability
- Unexplained equipment failure or faulted conditions
- Unexplainable dysfunction or unexpected operations of electrical equipment or controls relative to what has been usual and customary
- An electrical shock incident
- An electrocution
- An arc flash incident
- Abnormalities with the emergency power systems
- Provides means and methods to determine the "present state" of a power distribution system, its associated equipment, its functionality, and its reliability relative to the present needs of a building's or facility's functions and operations. (Business functions and operations change much faster than power distribution systems.)
- Provides means to determine the electrical and mechanical health of the power equipment and power distribution system and how long it will likely continue to function as originally designed and intended.
- Provides for visual inspections of portions or all of the existing power distribution system by electrical engineers experienced and well versed in power distribution equipment and power distribution system designs. (Often these inspections are the first since original installation.)
- Determine causes or sources of incipient points of electrical component or equipment failure.
- Determines and discovers defects, deficiencies, hazards, or weaknesses in existing electrical power distribution system installations and provides recommendations and solutions for enhancements or corrections prior to electrical dysfunctions or failures.

2.0 Why Perform an Assessment? (con't)

- Requirements by AHJs, electrical codes & standards, ordinances, statues, regulatory agencies, or federal departments (i.e., NEC Article 708.4, NFPA 99, NFPA 1600, DOE, DOD, DHS, or State Department requirements). Such "requirements" have increased since 9/11/2001.
- Grades issues in the order of importance and magnitude relative to their affect on personnel safety, facility functions, and business operations.
- Provides cost estimates to make corrections, maintain existing functionality, or enhance reliability.

However, the reasons for assessments listed above are commissioned after the fact, are usually very limited in scope, and are principally focused only in ameliorating the specific concerns or conditions at hand.

Another reason assessments are performed is that management may desire to have an independent review or second opinion of work performed by others. An independent assessment or inspection is often employed as a quality assurance method to review the contracted scope-of-work performed by a specific contractor. Assessments are often employed to determine if an existing or new electrical installation is in compliance with local electrical codes, the NEC®, applicable IEEE® Standards, the equipment manufacturer's installation and operational specifications, or best engineering and construction practices.

To provide a broader and much more important perspective, comprehensive assessments by an experienced professional electrical engineer are best employed to provide information to management on the 'present state' of specific PDS. The results of such assessments are extremely valuable in determining the remaining usefulness or reliability of electrical equipment as well as the compatibility of existing equipment with newly installed or planned electrical equipment expansions. An understanding of the remaining usefulness or reliability of electrical equipment can provide management with an opportunity to adequately and proactively budget for a systematic replacement or retrofit of existing electrical equipment that might be aged, dysfunctional, outdated, underrated, unreliable, or worn out.

Interconnecting dissimilar electric equipment or circuit breakers provided by different electrical manufacturers can often result in poorly coordinated overcurrent protection or unwanted tripping conditions. Comprehensive assessments can be employed to construct a framework or guide for preventive maintenance programs and planned equipment enhancements or replacements. Occasionally PDS assessments are performed to fully understand the liability the system may present for a reliable hospital operation.

3.0 Who Should Perform PDS Assessments?

PDS assessments should be performed by an experienced or professional electrical engineer who is intimately familiar with the design, compatibility, and functionality of sophisticated electrical equipment and complex interconnected power distribution systems. The selected electrical engineer or engineering firm should be familiar with automatic controls, protective relaying and coordination of circuit breakers, on-site emergency generators, emergency power equipment, automatic transfer switches, isolated power systems, grounding system, ground fault protection system, lighting control systems, and surge protective devices. The selected electrical engineer or engineering firm should also be familiar with applicable IEEE® standards as they pertain to commercial and industrial facilities and hospitals.

4.0 Before Beginning the Assessment Process

Several things need to be considered before beginning any assessment process. These include safety, scope of work, and the items and tools necessary to perform the assessment.

4.1 The Importance of Safety

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Before starting the PDS assessments remember that safety is always of paramount importance. Although it is the responsibility of facility management to assure the security at the facilities and to maintain a safe work environment, the electrical engineer performing the on-site assessments should be safety trained in accordance with NFPA 70E®, Standard for Electrical Safety in the Workplace.

Any electrical engineer performing the on-site assessments is responsible for his own safety and should reserve the right to discontinue any on-site activity if conditions are deemed to be unsafe. Safety procedures should be reviewed and understood by both the assessment party and the facility maintenance team. In addition to electrical safety, the electrical engineer performing the onsite assessments should be informed and made aware of any biological hazards that may be present during the course of his movements through and around the facilities.

4.2 Security is Also Important

The facility management should arrange for security cards, identification badges, and access to entry cards or security keys. The assessment engineering team also needs to be made aware of restricted areas or areas that may require staff personnel to provide an escort.

5.0 Clarify the Scope of Work

Clarify and document the "scope of work" before the assessment process begins. Before beginning any on-site assessments there should be a clear and documented understanding as to which equipment or portions of the PDS will be incorporated into an assessment program or study as well as any excluded portions. The understanding takes the form of a scope of work document that is drafted with the input of the assessment engineer and management of the commercial and industrial facilities. The scope of work needs to include the equipment that will be incorporated into the assessment. Examples of such engineering functions might include providing equipment, taking measurements, performing electrical or functional tests, or operating a facility's equipment. Such diligence in the beginning of the process is intended to prevent misunderstanding, distractions, or expectations of tasks not clearly covered in the scope.

It is also important for the electrical engineer performing any assessments to clearly identify any specific assistance that may be needed while on site and inform the management of the commercial and industrial facilities of any supportive roles that may be necessary by them, their associated staff, or their designated agents or contractors. Some support activities that may be necessary for the commercial and industrial management to provide are listed below.

- Provide an individual authorized to resolve questions and coordinate customer activities, as required.
- Provide an experienced electrical engineer or supervisor that is familiar with design documents and records to direct and assist Engineering Services personnel in any necessary equipment inspections.
- Provide and expedite any badge processes necessary to required entry and escorts as necessary.
- Inform the assessment engineer of any particular or specific safety requirement necessary to perform any activities on the customer's site.
- Provide maintenance or operations staff personnel that are familiar with the existing power distribution system who will accompany assessment engineer through the facilities and arrange for access to inspect the applicable electrical equipment.
- Assist in the collection of applicable manufacturing and construction record data that accompanied the equipment.
- Provide a timely response for all questions and submissions.
- Assist in providing access to the facility's electrical panels, and the assistance of an electrician or facilities technician familiar with the exact physical location of all electrical equipment, electrical circuits, and specific loads during the on-site work.
- Be responsible for collecting and provide all requested information concerning any or all specific as-built electrical distribution system.

6.0 What is Needed to Perform Assessments?

It is important that the electrical engineer performing the on-site assessments be effectively prepared and this includes knowing what is needed to perform the on-site assessment. Below is a partial checklist of items or support that is often involved with or required to perform the on-site assessments.

- Is safety equipment required?
- Are safety procedures required?
- Is test equipment or diagnostic equipment required?
- Is support personnel required?
- Are outside contractors required?
- Are power outages required?
- Is special equipment required?
- Are special tools required?
- Are cameras allowed?

7.0 After an Event: The "Interview Period"

If the on-site assessments are associated with a specific event, the selected engineer should start the process by interviewing the facility staff and all applicable or associated parties in order to gather as much historical data and information on the sequence of event as possible. Recollections and memories may reveal entirely different or conflicting descriptions of occurrences or sequences of events. Begin to quantify as many variables as possible for your assessments and analyses. Below are some examples.

- What events occurred or did not occur?
- What equipment was involved?
- When did the events occur?
- At what times and on which days?
- Who was present?
- What do they remember?
- What were the sequences of events?
- Is there any damage equipment available for inspection?
- What conditions or combination of conditions could have caused the conditions reported? Begin to formulate conditions, pictures, and scenarios in your mind.

7.0 After an Event: The Interview Period (con't)

- Ask for and review all available and applicable documentation.
  - One-line diagrams, inspection reports, test reports, original specifications, etc.
- How long have the systems been in place?
- What is the type and sequence of operation?
- What is the history of construction?
- What is the history of facility operations?
- Were there any previous issues, incidents, or concerns?
- Determine and select the point to begin the inspections / assessments.
- Coordinate action plans with the customer.

8.0 General On-Site Assessments and Data Collection

Electrical equipment should be installed, operated, serviced, and maintained only by properly trained and qualified personnel. No responsibility is assumed by Schneider Electric for any consequences arising out of the use of this material.

All power distribution systems are different and dynamic. The electrical engineer performing the on-site assessments should have a one-line diagram to study and become familiar with the operational characteristics, construction, and limits of the equipment to be assessed. It is important to know what electrical codes were in place when the equipment or system was originally constructed or set in place. Not all municipalities and states employ exactly the same electrical codes and standards. Any special electrical code requirements in the specific location need to be taken into consideration. The dimensions of the facilities under assessment are also an important consideration. Are there any outside influences and conditions to consider such as switching operations by the local electrical utility, atmospheric disturbances, or recent changes in configuration or operation of the facility's internal electrical distribution systems? It is important to quantify as many variables as possible as part of any assessment program.

8.0 General On-Site Assessments and Data Collection

8.1 A Recommended or Suggested Starting Point

The system configuration is based strictly on the specific secondary winding configuration of the power class or distribution class transformer supplying the service and exactly how it may or may not be referenced to earth. The system configuration is NOT based on the connection of any specific load or loads. Some of the data collected during the inspection processes are similar or identical to the data collection for short circuit study, time/current coordination study, or an arc flash study. The only difference is that the electrical engineer might be principally focusing on the installation and present state of the equipment. For example;

- How many sources of power? (XMFR, generators, UPSs, MG Sets,)
- Who is the service provider?
- Who owns the service transformers?
- How are the service transformers, generators, UPSs, or MGs configured or referenced to earth?
- Is the system voltage referenced to earth via a solidly grounded connection, a high or low resistively grounded connection, or an inductor?

8.2 Assessing Power Class Transformers

Following is a list of specific things to look for when assessing power class transformers (greater then 500 KVA).

- What is the size of the transformer in KVA?
- What are the primary and secondary winding configurations?
- What are the primary and secondary voltages?
- What is the present tap setting?
- Does the transformer have a “no load” tap changer or a “load” tap changer?
- What is the percent impedance (%Z) of the transformer?
- What is the cooling means for the transformer?
- What is the condition of transformer?
- What is the temperature gauge reading? (Present temperature and the maximum temperature indicated)
- What is the liquid level indication?
- Nitrogen gas blanket?
- Is there a nitrogen gauge or regulator present?
- Are there fluid leaks present?

8.0 General On-Site Assessments and Data Collection (con't)

- Are there any evidence or indications of previous insulation fluid leaks?
- What are the types of primary and secondary protection?
- What is the type of bonding and grounding method employed?

Power class transformers located outside of the facility must have enclosure types that are rated for the specific application, environment, and location. The transformer must be accessible to qualified personnel and protected from unauthorized persons for their personal safety and for the security of the facilities operations. Because of local ordinances the transformer might require security fencing or camouflage. Such transformers require appropriate safety labels or signs. Power class transformers located inside of the facility must be dry types or filled with non-flammable liquid. Such transformers located indoors may be required to be located in a sealed and secured vault or placed in a room with a specific fire rating. Environmental considerations are very important to the placement of indoor transformers. Since such transformers must be in specific fire rated rooms or locations, accessibility to the transformer, heat dissipation and cooling for the transformer and security for the transformer are always an issue or concern and consideration. The importance of a large volume of open space around indoor power class transformers is for heat dissipation for the transformer windings. Because of the required open space around large indoor transformers, such areas are routinely employed after the initial construction as a storage area for excess materials or records.

8.3 Assessing Emergency Generators

The following is a list of specific things to look for when assessing emergency generators.

- Is there any paralleling of transformer with other transformers or emergency generators?
- What is the kW and KVA rating of the emergency generators?
- How are the Xo terminals of the transformer and generators bonded to ground?
- Is the frame of the transformer and the emergency generators effectively bonded to earth and to each other via a permanently connected low impedance path?
- What is the maximum power factor? (80%?)
- What is the winding configuration?
- What is the output voltage?
- Is there other applicable nameplate information?
- What is the type of bonding and grounding method employed?
- Paralleling?

8.0 General On-Site Assessments and Data Collection (con't)

- What is the percent (%) pitch?
- Are there any protective relaying issues?
- What is the fuel source for the prime mover?
- What is the state of the generator's start batteries?
- What is the capacity and condition of the generator's day tank?
- How is the generator controlled and regulated?

8.4 Assessing Distribution Class Transformers

The following is a list of specific things to look for when assessing distribution class transformers (500 KVA or less).

- Size in KVA
- Primary and secondary winding configurations
- Primary and secondary voltages
- Percent impedance (%Z)
- Is the transformer readily accessible? (Refer to NEC® 450.13)
- Is there sufficient space around dry type transformer to allow for adequate cooling? [Refer to NEC 450.9 and 450.21(A)]
- What is the physical condition of the transformer?
- Is the transformer audible? (As dry type transformers age or become overloaded over a long period of time, thermal stresses can cause the laminations to begin to separate. Consequently, the normal 60 Hz hum sounds more like a continuous high frequency scream.)
- Types of primary and secondary protection?
- Size and type of primary and secondary conductors? Are they underrated? [Refer to NEC 210.20 and 240.92(B)(2)(4)]
- Type of bonding and grounding method employed?
- How and where is the Xo terminal connected to the building steel?
- Is the transformer ventilation adequate to prevent overheating and a risk of fire? (Refer to NEC 450.9). "The ventilation shall be adequate to dispose of the transformer full-load losses without creating a temperature rise that is in excess of the transformer rating. Transformers with ventilating openings shall be installed so that the ventilating openings are not blocked by walls or other obstructions. The required clearances shall be clearly marked on the transformer."

8.0 General On-Site Assessments and Data Collection (con't)

- Is there accessibility to each transformer? (Refer to NEC 450.13) "All transformers and transformer vaults shall be readily accessible to qualified personnel for inspection and maintenance."
- Is there dry type transformer installed indoors? (Refer to NEC 450.21) "Dry-type transformers installed indoors and rated 112.5 KVA or less shall have a separation of at least 305 mm (12 in.) from combustible material unless separated from the combustible material by a fire resistant, heat-insulated barrier." "Individual dry-type transformers of more than 112.5 KVA rating shall be installed in a transformer room of fire-resistant construction. Unless specified otherwise in this article, the term 'fire-resistant' means a construction having a minimum fire rating of one hour."

8.5 Assessing Service Equipment

Following is a list of specific things to look for when assessing the service equipment:

- The types of primary and secondary protection
- The type of service equipment? Is it a switchboard or is it switchgear?
- What is the NEMA rating and type of equipment relative to the surrounding environment?
- The manufacturer, brand, and nameplate data
- The type of main and feeder overcurrent protective devices
- What are the settings of the circuit breaker's protective functions? Is there apparent coordination? (Refer to NEC® 110.9)
- What are the dates of installation? (This will determine which electrical codes are applicable at the time of installation.)
- Is there a ground-fault protection system? If so, where?
- Is the ground-fault protection system functional?
- Was the ground-fault protection system tested when first installed? If so, where are the records? (Refer to NEC 230.95)
- Is there a main bonding jumper? (Refer to NEC 250.24)
- The neutral disconnect link
- Are shipping splits ground bus and terminals made up?
- The type and size of service and feeder conductors
- Is there a neutral with the service entrance cables? (Refer to NEC 250.24(C)
- How are they terminated? Type of lugs?
- Are the lugs effectively torqued? Was the correct Grade 5 or higher rated hardware utilized?

8.0 General On-Site Assessments and Data Collection (con't)

- Are service and feeder cables effectively braced, laced, and secured? [Refer to NEC 300.20, 408.3(A)(1), and 408.3(B)].
- What is the type of bonding and grounding method employed?

8.6 Assessing Downstream Equipment

The following is a list of specific things to look for when assessing downstream dead front switchboards, panelboards, load centers, power panels, and fused disconnects.

- The size and status of the neutral disconnect link
- What are the models, types, and ages of the equipment?
- What are the types, sizes, ratings of all Overcurrent Protective Devices (OCPDs)?
- Is the equipment listed for the environment?
- Are there environmental concerns?
- Is there an effective ground fault return path?
- What is the intended ground fault return path?
- What is the condition of the interior?
- Are there any obvious objectionable neutral-to-ground bonds?
- Is there sufficient clearance around the equipment to avoid a fire hazard? (Refer to NEC 110.26 and 408.18)
- Has the limiting temperature of the equipment been exceeded? [Refer to NEC 110.13(B) and 408.3(B)]
- Are the panelboards and sub-panels properly protected? (Refer to NEC 408.36)
- Are there any tap rule violations? [Refer to NEC 240.21(B)(2)(1) - tap rule section]
- Are the installed cables sized correctly?
- Are all OCPDs correctly rated and sized?
- Proper temperature rise rating of cable relative to OCPD and environment (Refer to NEC 310.15)
- Are there six cycles of separation for ground fault protection? (Refer to NEC 517.17)
- Do isolated power systems function and operate as designed and intended? When was the last time they were tested? Were the test results documented, recorded, and available for retrieval and review?

8.0 General On-Site Assessments and Data Collection (con't)

8.7 Assessing New Electrical Equipment Installations

The following list includes some typical reasons for assessing new electrical equipment installations:

- To insure and verify that the electrical equipment is in compliance with the purchase specifications and intended power distribution system design by the Engineer of Record.
- To insure and verify that the electrical equipment has been installed safely as designed and intended and in accordance with applicable codes, standards, or best practices.
- To document initial assessments to serve as a benchmarks or references for future inspections.
- To insure that new electrical distribution equipment is effectively coordinated with any existing electrical and power distribution equipment.

8.8 Assessment of Electrical Room Construction

- What are the cooling and humidity requirements for equipment?
- Are there ventilation requirements for specific equipment rooms?
- What are the minimal spaces between physical structures and other electrical equipment?
- Is the equipment adequately accessible for maintenance and servicing personnel?
- What are the security accessibility and requirements?
- Emergency Power-Off (EPO) installations and their locations.
- Is the equipment NEMA 1 or NEMA 3R?
- Are service and load conductors rated for application and environmental conditions?
- Are dissimilar circuit breakers being employed in multiple-ended power distribution equipment (multiple sources)?
- Review and understand the GFPE system as meeting the NEC.
- Storage must remain outside the electrical equipment area.
- Are there adequate fire alarms?
- Is all electrical equipment effectively bonded and grounded?
- Is there effective lighting within electrical rooms or closets?
- Have equipment installation requirements and guidelines been provided by the electrical equipment manufacturer?
- Have operations and maintenance manuals been provided by the electrical equipment manufacturer?

8.0 General On-Site Assessments and Data Collection (con't)

- What are the existing startup and testing requirements?
- What are the proper lock-out/tag-out requirements?
- Are the appropriate danger and warning labels properly affixed? Have all of the "inform and warn" requirements been satisfied?
- Is there a need for a housekeeping pad under the electrical equipment?
- Have the proper locations within a specific building or facilities for the placement of service equipment, distribution equipment, power panels, motor control centers, ATS Units, battery banks, UPS Units, on-site generators, etc., been appropriately selected?
- Are there flooding concerns from either external or internal sources?

NOTE: Short circuit and time/current coordination studies are necessary to insure that all overcurrent protective devices are effectively coordinated and properly set.

- Are there any structural/seismic requirements for the electrical room?
- Are there any structural and bracing requirements for the electrical equipment enclosures?
- What are the structural and bracing requirements for overhead busways, busducts, and conduits?
- Is there a need for floor drains or sump pumps in electrical rooms?
- Are there temperature and humidity requirements necessary for the electrical rooms?
- Is the appropriate protection installed to protect the electrical equipment from or vermin infestations?

8.9 Assessments May Involve Some Testing

- What are the proper temperature rise ratings of the cables relative to the OCPDs and the environment?
- What is the present state of all insulation levels relative to manufacturer's specifications or previous test results? (i.e.; deterioration or shorted windings, excessive leakage current, corona damage)
- Are the torque values as designed and intended?
- What is the present state of contact resistances of all fused power switched and power circuit breakers?
- Do movable parts operate as designed and intended?
- Do protective devices operate as designed and intended? (i.e.; long time overloads, short circuit protection, instantaneous overload, and ground fault protection?)
- Are the setting of all protective devices correctly placed on the proper pickup and time delay settings?

8.0 General On-Site Assessments and Data Collection (con't)

- Is there any deterioration of insulating fluids? If so, why? What is the root cause of any deterioration?
- Is the equipment effectively bonded and grounded via a low impedance path?
- Is there an effective grounding system?
- Is the electrical equipment functioning safely as originally designed and intended?
- Are there any deteriorated components, parts, or equipment that need to be replaced or repaired?

Documented findings serve as benchmarks and reference for future testing.

Electrical equipment should be installed, operated, serviced, and maintained only by properly trained and qualified personnel. No responsibility is assumed by Schneider Electric for any consequences arising out of the use of this material.

9.0 Loss Experience for Electrical Equipment Failures

The information that follows is data collected from a single insurance company, FM GLOBAL® (formerly Factory Mutual Global). The following charts present FM Global's loss data showing losses caused by electrical equipment failure within the United States during specific time periods. It is extremely important to note that the data is just from one insurance company. If one considers the number of other large insurance companies within the United States, one can gain an appreciation for the total magnitude of claimed losses annually just from electrical equipment failures. What is also extremely important to note is that most actual electrical losses are recorded or claimed as losses to the insurance underwriter a specific commercial or industrial facility that experienced losses involving electrical equipment.

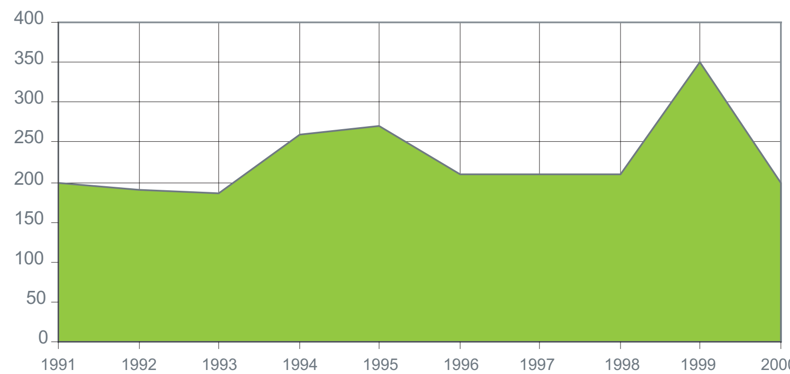
9.0 Loss Experience for Electrical Equipment Failures (con't)

The charts below presents FM Global's loss data showing losses caused by electrical equipment failure per specific types of equipment. Many of these losses involved insulation breakdown. It is believed that some of these defects could have possibly been detected by preventive maintenance and testing. Consequently, the direct cost could have been greatly reduced. The losses also included fires caused by electrical ignition and electrical breakdown due to defective electrical insulation in critical equipment.

Table 1: **Electrical Losses Reported to FM Global®** (1991-2000)

Equipment	Number	Gross US$ (Millions)
Transformers	1000	492
Cable / Wiring / Bus	893	362
Switchgear / Circuit Breakers	602	254
Generators	174	166
Motors	580	145
Misc. Electrical Apparatus	261	48
Total	**3510**	**1467**

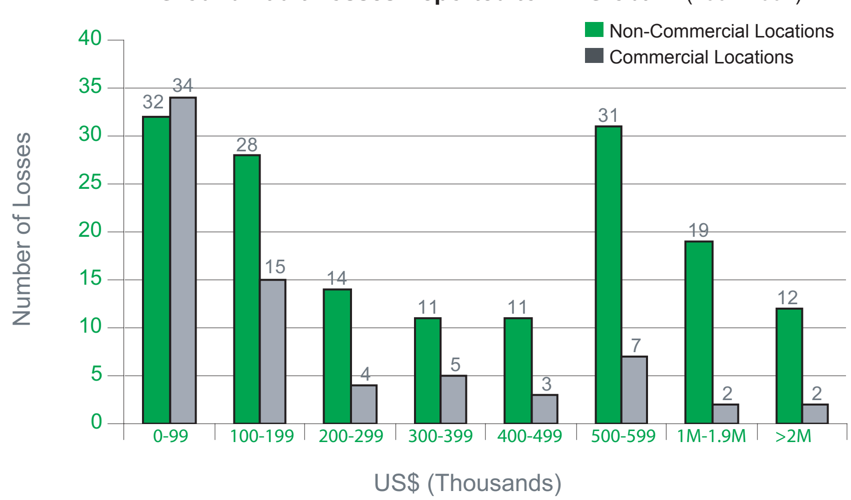
FM Global® Customers Gross Electrical Losses (US$ Millions)



The chart below equates to one large claim every two weeks from a phase-to-ground arcing fault.

NOTE:
The NEC is a minimum construction and installation 'requirement' document. The NEC is NOT a design or performance standard. "Minimum requirements" are often insufficient for the construction and installation of mission-critical facilities such as large healthcare facilities and hospitals.

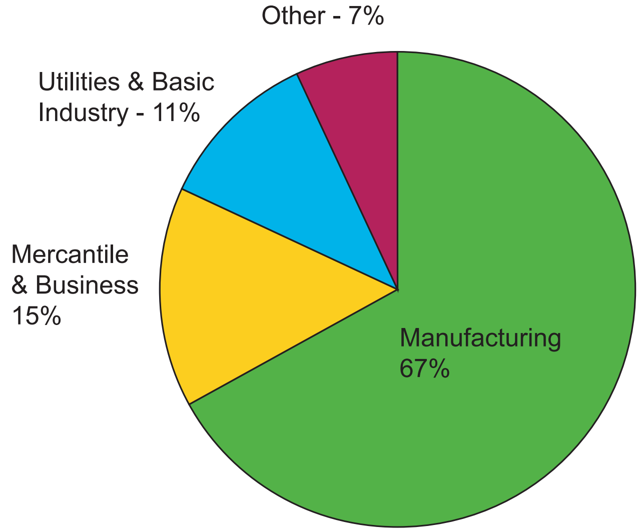
Ground Fault Losses Reported to FM Global® (1992-2001)



9.0 Loss Experience for Electrical Equipment Failures (con't)

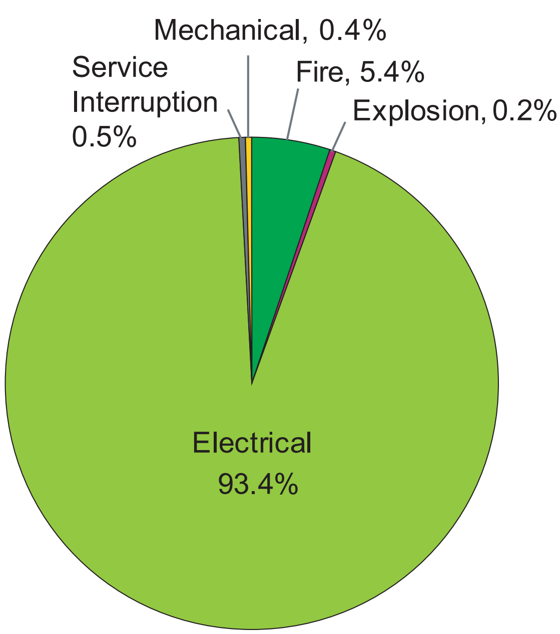
The pie chart (right) shows the types of industries that have reported losses in which the absence of infrared thermography was a factor. The losses included fires caused by electrical ignition, and electrical breakdown caused by electrical faults.

Source: FM Global Clients

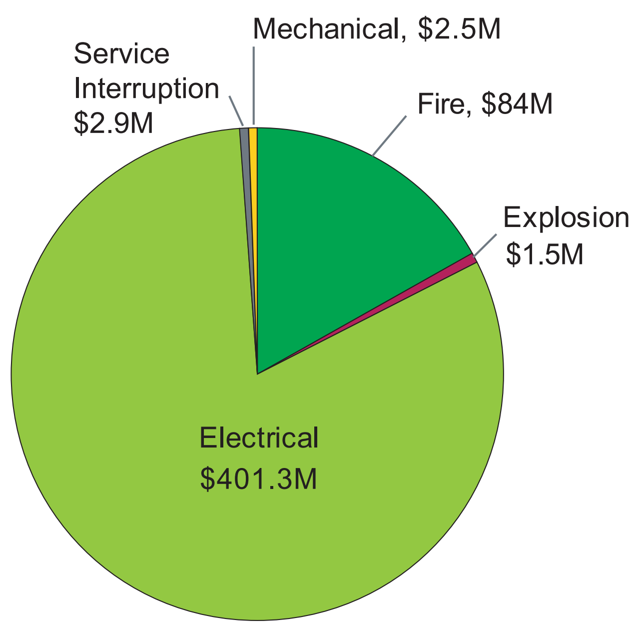


The charts below present FM Global loss data showing losses caused by electrical breakdown of transformers. Some of these symptoms that initiated the failure had been detected through dissolved-gas-in-oil analysis. Therefore, the loss and repair cost was greatly reduced or possibly eliminated. Losses also include fires caused by electrical ignition within the transformer, generally initiated by internal arcing.

Transformer Losses by Hazard (%)



Transformer Losses by Hazard ($US)



9.0 Loss Experience for Electrical Equipment Failures (con't)

Losses from lack of motor maintenance and testing are shown below:

1989 - 1999 Losses to Induction, Synchronous or Direct Current Motors

Direct losses; totals do not include subsequent or downstream damages.

Motor Type	Damaged Part	# Losses	Gross US$
Induction	Stator Winding	42	$ 6,709,640
	Rotor Winding	9	$ 4,854,250
	Mechanical Components	6	$ 2,776,190
	Bearings	5	$ 752,807
	Electrical Components	7	$ 707,919
Synchronous	Stator Winding	13	$ 13,738,065
	Rotor Winding	7	$ 2,523,742
	Electrical Components	5	$ 1,932,915
	Mechanical Components	3	$ 879,730
	Bearings	1	$ 59,109
DC	Rotor Winding	15	$ 21,759,284
	Electrical Components	10	$ 7,591,258
	Mechanical Components	4	$ 3,424,355
	Stator Winding	7	$ 2,429,184
	Bearings	1	$ 138,058

10.0 References

- Power distribution systems or PDS is specifically referring to the electrical power systems.
- ANSI refers to the American National Standards Institute.
- IEEE refers to the Institute for Electrical and Electronic Engineers, Inc.
- NEMA refers to the National Electrical Equipment Manufacturers Association.
- NFPA refers to the National Fire Protection Association.
- NEC refers to the 2011 Edition of the National Electrical Code.
- FM Global