

A **PROACTIVE** **APPROACH** TO

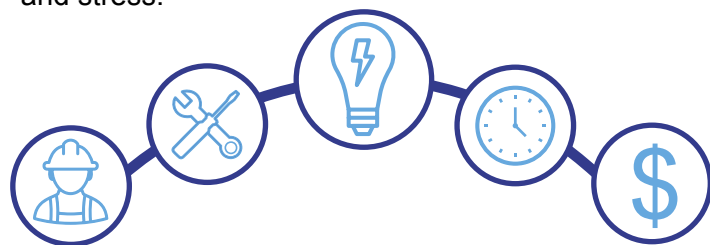
ELECTRICAL MAINTENANCE



Implementing the right maintenance strategy positively impacts your facility's bottom line. Increase your facility uptime by doing the right thing for you and your personnel.

PREDICTIVE MAINTENANCE: AN IMPORTANT ELEMENT IN YOUR UPTIME STRATEGY

Every facility across the globe relies on electrical power today. Most industrial and commercial facilities solely rely on their utility power feeds and transformers while other mission critical facilities depend on generators and Uninterruptible Power Supplies (UPS) for their back up power redundancy. A common factor in determining the reliability and uptime of an electrical system is the condition and the availability of the power distribution equipment such as medium voltage and low voltage switchgear, transfer switches and MCCs used in the downstream. Historically, all preventive maintenance strategies have been put in place on the cable connections, joints, busbar splices and other movable parts that shows physical symptoms of major wear and tear and stress.



Compared to other types of rotating equipment, the power distribution equipment makes significantly less noise or no noise during their normal operation and perhaps the reason why they get less to no attention.

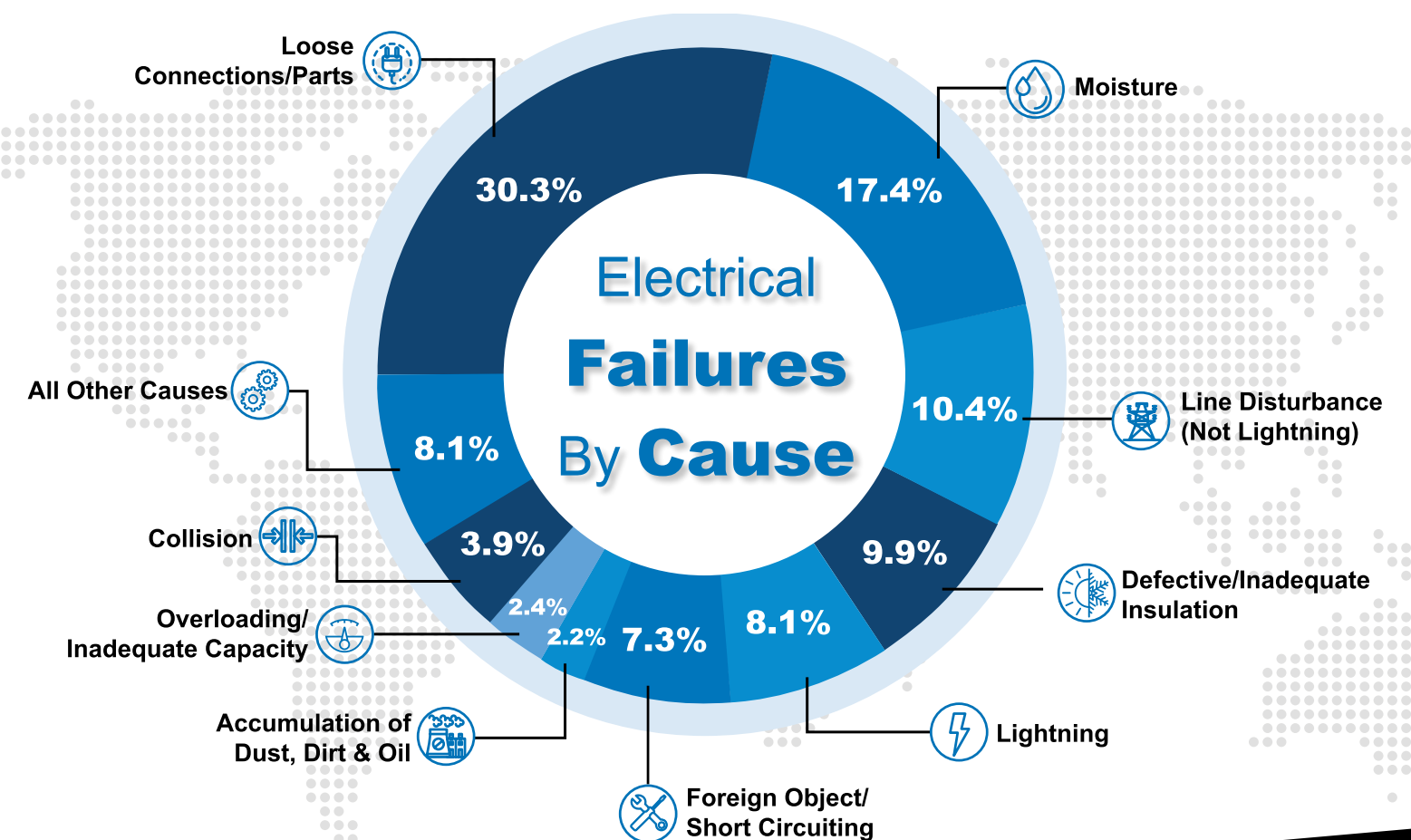
Additionally, the availability of skilled and trained personnel to perform the maintenance related activities combined with production pressures that intervene to perform the maintenance routines make it more difficult. Most facility owners and operators follow either a three year or five year electrical maintenance routines or in many cases only react to an unplanned power outage.

Often overlooked with the electrical power distribution equipment is the progressive addition of loads and their effect on the overall system.

For example, a system designed and commissioned with a 2000 Amps calculated load a decade ago in a collocation data center or an industrial manufacturing facility might actually be running well over 30-50% above the designed parameters today.

Since most systems are already designed conservatively considering the marginal future load, this may not create a major problem in the short run. However, the same trends of adding additional loads over time without considering their effects like surge characteristics and duty cycles will negatively impact the insulation and performance characteristics that could potentially lead to an unplanned outage.

The inconvenient truth about preventable failures of power distribution equipment is that it takes down an entire production line or in some cases the complete facility shuts down. In contrast, many processes are still operable in the event of a failure in just one single piece of downstream equipment such as a pump or motor in a manufacturing process.



Data Source: Hartford Steam Boiler Insurance Co.

Most electrical systems are designed for 40°C - 45°C ambient temperature. Every **10°C rise** in temperature **shortens** the average **reliability** of electrical components by **50% percent**



Electrical system breakdowns are a leading cause of equipment and business interruption losses. It's a growing problem and the losses can be substantial – electrical systems constitute a major percentage of a property's total value.

WHAT CAUSES YOUR ELECTRICAL EQUIPMENT FAILURE?

The percentage of total electrical failures by cause type published by a renowned industrial and facility insurance provider indicates that loose connections/ parts contribute to over 30% of all electrical failures and a major cause for power outages, followed by 17% for moisture and 10.4% for line disturbance.

ELECTRICAL MAINTENANCE PRIORITIZATION: WHERE DO I START?

Electrical maintenance prioritization is one of the major concerns that many facility owners and operators encounter. In many instances, the equipment is neither brand-new nor age-old. For example, a twenty-five-year-old facility can have electrical equipment from 3 to 20 years old. How should I prioritize maintenance on my equipment?

IEEE 493 Gold Book standards and the famous reliability bathtub curve can paint an overall picture of how your equipment rank given the installation and reliability statistics of the various types of electrical equipment.

The Bathtub Curve suggests that many product failures occur during the infant mortality period or early stage period because of product manufacturing defects, quality issues, followed by useful life where the failures are either stress related, human error or due to improper maintenance, and wear out failures due to aging. A simple rule of thumb is to always start with critical equipment within your facility which creates a single point failure or take the overall system down, followed by any equipment that shows impending failures. Consider the economic loss factor due to a power outage and the cost of avoidance while prioritizing your equipment.

Loose Connections contribute to over 30% of all electrical failures and a major cause for power outages.

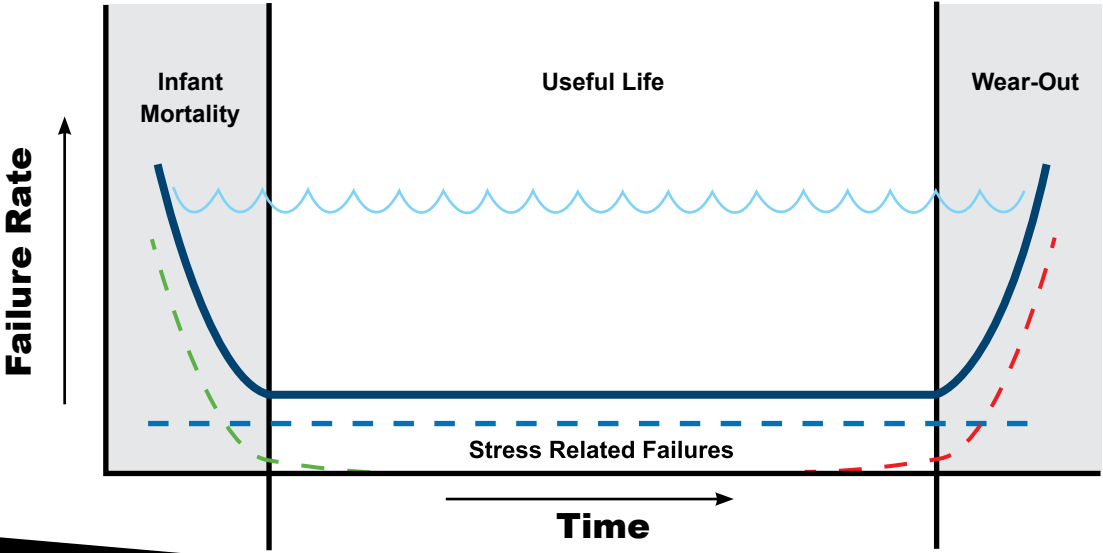
Source: Major industrial & Facility insurance provider

Equipment Type	Expected Useful Life Period (years) ¹
Transformers	25 - 30 years
Circuit Breakers	15 - 20 years ²
Switchboards/ Switchgears	30-40 years
MCC/Motor Starters	20-30years
Panelboards	30 years
Motors	18-25 years
Generators	5-20 years
UPS	10 years
Luminaire	20years
Capacitors (Power factor correction)	17 years
VFDs	20 years
Cable/Wire	30-40 years

¹ Life Expectancy info collected from ABB, CDA, CDM, IEEE Gold Book and Siemens.
² By year 10, 50% of circuit breakers don't function properly per specs. By year 20, 90% don't function properly.

The Bathtub Curve

Most failures during the useful life are due to improper maintenance and human error.





Inspections performed at **non-peak hours** due to the **facility and personnel availability** can greatly affect the **relevancy** of the **measured data**

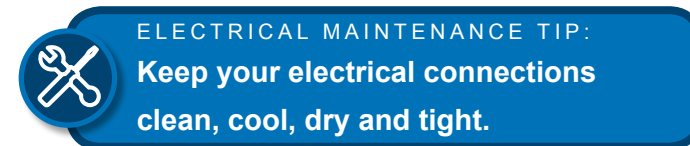
PROACTIVE AND PREDICTIVE MAINTENANCE: A SIMPLIFIED AND APPLICABLE SOLUTION

Most of the electrical equipment failures occur in power distribution equipment either due to loose connections (30.3%) or insulation failure (9.9%). While insulation breakdowns of the equipment can be identified through partial discharge surveys and tests.

It is particularly difficult to identify the cause of loose connections as they could be due to both mechanical and electrical issues.

An electrical failure due to loose connection is a current fault and it could be due to under torqued connections, mechanical load on the terminals, varying load conditions, duty cycles, cable crimping, and training. Most of these connections fail because of the excessive heat rise as a result of increased resistance at the connections. Both these events can be monitored without interrupting the facilities. While Infrared Thermography inspections are a most common method for predicting temperature

anomalies, it is important to understand the transitivity settings of the connections monitored and proper calibrations of the IR Camera.



Hot Spots Occur Due To:

- Loose connections
- Vibration
- Mechanical stresses due to high magnetic forces during faults or high starting currents.
- Aged/unmaintained equipment
- Unbalanced loads
- Overload conditions
- Harmonics caused by non-linear loads
- Ambient conditions and thermal cycles

Equipment operating temperature significantly impacts the overall useful life. Most electrical systems are designed for 40°C - 45°C ambient temperature. Every 10°C rise in temperature shortens the average reliability of electrical components by 50% percent.

THERMOGRAPHY 101

Thermography methods use aiming an Infrared (IR) Camera at the electrical connection or potential hot sources inside the electrical equipment to measure the temperature. Open door thermography inspections demand heavy PPE, certified thermographers and personnel working in the close proximity of the energized components.



Closed door thermography utilizes an IR viewing window(s) installed on the equipment through which the IR camera is directed at the hot spots. It is often difficult to inspect all critical connections in an electrical panel with the IR window's limited field of view (FOV) due to the location of the window, equipment complexity, and busbar construction. Though most IR windows are available in sizes ranging from 2" – 20" diameter, larger FOV is unattainable without using bigger/more



windows or highly expensive custom windows. IR windows installation in arc rated equipment further poses a threat to the arc rating of the gear, structural integrity and also raises many warranty concerns over the equipment from the manufacturers.

IR Thermography is a great tool to identify the temperature anomalies but requires qualified and certified thermographers to perform the work. Most insurance companies and standards require the IR inspections to be performed on systems under an energized condition that replicates the normal operating load or at least on 40% of the rated load.

Inspections performed at non-peak hours due to the facility and personnel availability also affect the relevancy of the measured data. As a result of inspections, thermographers typically issue a detailed report identifying the equipment with the corresponding image, temperature rise finding and recommended actions. Few high-end loss prevention insurance providers and thermographers provide detailed repair estimates and cost avoidance details while taking the production downtime into consideration.

Let's Compare

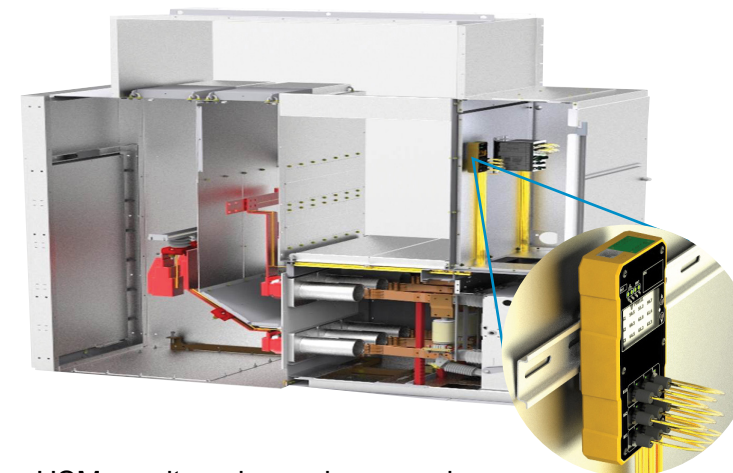
Open Door Thermography vs IR Windows vs Hot Spot Monitor



Description	Open Door Thermography	IR Windows	Hot Spot Monitor
Exposure to incident energy	High	Medium	None
Personal Protective Equipment (PPE)	Required	Required	None
Device Calibration	Required	Required	Not required
Special training, skills and certifications (Thermography)	Required	Required	Not required
Data logging and trending capabilities	Manual/No	Manual/No	Alarm/Relay Output
Access to critical connections/complex system geometry	No	No	Yes
Alarm capability	No	No	Yes
Integration with existing SCADA/ DCS systems	No	No	Yes
Ambient measurement	No	No	Yes
Installation	N/A	Complex	Simple
Structural Degradation	N/A	Yes	No
Inspection frequency	Semi/Annual	Quarterly	Continuous
Technology	Non- contact	Non- contact	Non-conductive contact

GRACESENSE™ HOT SPOT MONITOR - A PREDICTIVE MAINTENANCE TOOL

GraceSense™ Hot Spot Monitor (HSM) is a continuous temperature monitoring device that can spot temperature abnormalities in electrical connections of power distribution systems such as busbars, MCCs, drive panels, switchgear, and bus ducts etc.



HSM monitors, logs, alarms and enables the user to trend temperature variations that are indicative of a potential fault. HSM, a component of the predictive maintenance system when integrated with facilities electrical preventive maintenance program (EPM) as defined in NFPA 70B enables the user to plan and schedule maintenance tasks that will avoid unplanned shutdowns and monetary damages.

HSM allows the user to set, monitor, record and retrieve the temperature data of critical connections in an electrical equipment. The unique non-conductive fiber optic technology with secured connections allows simple field installation in low, medium and high voltage electrical systems up to 80kV.

Our safety-by-design philosophy combined with HSM's remote monitoring capabilities eliminates the workers' exposure to high incident energy and loss of production due to unplanned shutdowns.





Where's the money?

Justifying Predictive Tools with ROI

MAINTENANCE IS NOT JUST A PRODUCTIVITY AND UPTIME METRIC: A PERSONNEL SAFETY REQUIREMENT

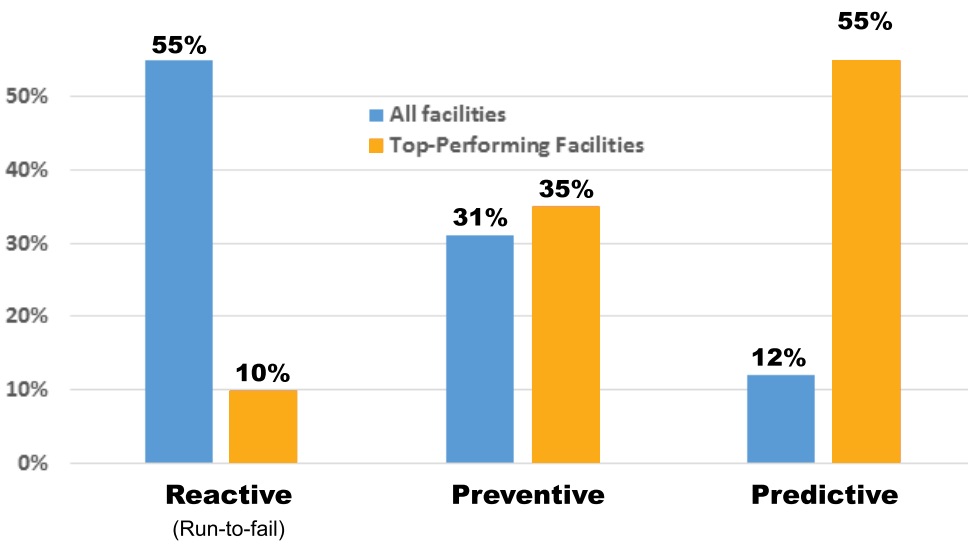
Maintenance is an enforceable code under OSHA. NFPA 70E states that equipment owner shall be responsible for maintaining the equipment and documenting the maintenance records to reduce workers exposure to electrical hazards. The standards also state that the maintenance shall be performed per manufacturer recommended guidelines or industry consensus standards such as NFPA 70B, or ANSI/NETA MTS.

WHAT IS YOUR ELECTRICAL MAINTENANCE STRATEGY?

As referenced in Dept. Of Energy, O&M Guide, top-performing facilities utilize 45-55% predictive maintenance programs, compared to 25-35% preventive maintenance and 10% reactive or run-to-fail maintenance. While a top performing facility and an average facility both spend about the same on preventive maintenance programs, the major difference is on how they compare on the predictive and run-to-failure metrics. This chart below gives a great indication of current maintenance trends and their maturity models.

Maintenance Type Comparison

Top performing facilities spend more than half of their maintenance budgets on predictive maintenance programs.



Sample ROI Calculator	
Cost of Failed Equipment	\$16,000.00
Cost of Spares and Logistics	\$3,500.00
Cost of Labor/Hr.	\$150.00
No. of Technicians	3
No. of hours required to perform the repair	8
Inventory/Production Loss	\$15,000.00
Revenue loss from the downtime	\$35,000.00
Total Labor Cost	\$3,600.00
Cost of the one shutdown	\$73,100.00
No. of avoided shutdowns	3
No. of Years	5
Total Savings from avoided shutdowns	\$219,300.00
Cost of Predictive Maintenance Tool Investment	\$45,000.00
ROI	387.33%
Annualized ROI	37.27%

Note: The above calculations are for illustrative purpose and provide reference for some of the key variables to consider in calculating the Return on investment(ROI). Actual ROI vary with user defined unique set of inputs.

Maintenance Methodologies

Pros and Cons

Reactive Maintenance (Run-to-Failure)

**Pros:**

- Minimal cost
- Minimal staff
- Minimal prep time

Cons:

- High downtime costs
- Increased labor cost with overtime.
- Inconsistent downtime
- Inefficient use of resources

Cost of Downtime:

\$\$\$\$\$

Preventative Maintenance (Time-Based)

**Pros:**

- Increased asset life
- Cost effective
- Reduced equipment failures
- 12-15% Cost savings over reactive maintenance

Cons:

- Failures still likely to occur
- Labor intensive
- Includes unneeded maintenance
- Damages arising from performing unneeded maintenance

Cost of Downtime:

\$\$\$

Predictive Maintenance (Condition-Based)

**Pros:**

- Increased asset life and availability
- Full visibility of the asset
- Decrease d equipment or process downtime
- Decrease in cost of labor and parts
- Maintenance on demand
- 8-12% cost savings over preventative maintenance

Cons:

- Higher upfront costs for monitoring equipment
- Staff training to interpret the data
- Justifying long-term savings with management

Cost of Downtime:

\$\$

Reliability Centered Maintenance (Hybrid Model)

**Pros:**

- Most effective maintenance program
- Minimize frequency of overhauls
- Reduced sudden equipment failures
- Increased component reliability
- Root cause analysis incorporated

Cons:

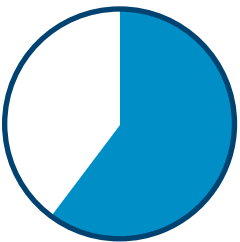
- Significant upfront costs, equipment and training
- Justifying long term savings with management

Cost of Downtime:

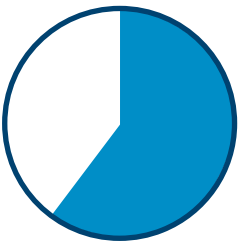
\$

The results further indicated that companies implementing predictive maintenance have seen:

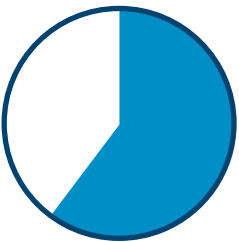
35 - 45%
Reduction in
Downtime



20 - 25%
Increase in
Productivity



25 - 35%
Reduction in
Maintenance
Costs



Data Source: Dept. Of Energy, O&M Guide

COMPARISON OF MAINTENANCE METHODS

Is Predictive Maintenance an answer to all your maintenance needs? Unlike the run-to-failure method, both preventive and predictive maintenance methods fall under the proactive maintenance category. Though the preventive and predictive methods share a common category, the principles, strategy, and implementation methods are different and in some cases a bit complex for the predictive tools. The chart below shows the pros and cons of various maintenance methods. A robust maintenance program will include the elements of both preventive and predictive maintenance tools.

Benefits of Predictive Maintenance:

- Avoid business disruption
- Enhance productivity and uptime
- Extend the equipment useful life
- Reduced insurance premiums and regulatory compliance

Things-to-consider for Predictive Maintenance tools:

- Impact of the asset failure in case of unexpected shutdown
- Production downtime
- Repair costs before and after failure
- Available redundancy
- How long does it take to repair the asset
- Availability of replacement parts



Companies implementing **predictive maintenance** have seen a **35 - 45% reduction in downtime**

ELECTRICAL DAMAGES BEYOND EQUIPMENT AND DOWNTIME

A research report published by National Fire Protection Agency (NFPA) in 2017 noted that 37,910 fires in industrial and manufacturing properties were reported for the period 2011-2015 which included 7,770 structure fires.

Of all the structure fires, Electrical distribution and lighting equipment were involved in 24% and heating equipment was involved in another 16% of these fires.

Another report of non-fire, non-rescue electrical incident data published by NFPA in 2014 noted 95,700 incidents due to arcing or shorted electrical equipment, and 23,600 incidents due to overheated motor or wiring that contributed to almost one-third of all the reported incidents.

Avoiding a catastrophic electrical equipment failure will not only save the equipment and the downtime but can greatly help to avoid significant damages to the property and personnel.

Electrical equipment failure and bearing failure that resulted in motor overheating triggered two large-loss fire incidents in 2016. The financial losses were listed as \$17.6 Million and \$13 Million – NFPA Large-loss Fire Report 2016.

ELECTRICAL SAFETY CONNECTION TO EQUIPMENT MAINTENANCE: NFPA 70E

Article 100 Maintenance, Condition of

The state of the electrical equipment considering the manufacturer's instructions, manufacturers recommendations, and applicable industry codes, standards, and recommended practices.(2018)

Article 110.1(C) Condition of Maintenance

The electrical safety program shall include elements that consider condition of maintenance of electrical equipment and systems.

Article 130.1(4) Normal Operating Condition

Normal operation of electric equipment shall be permitted where a normal operating condition exists.

A normal operating condition exists when all of the following conditions are satisfied:

- 1) The equipment is properly installed.
- 2) The equipment is properly maintained.

- 3) The equipment is used in accordance with instructions included in the listing and labeling and in accordance with manufacturer's instructions.
- 4) The equipment doors are closed and secured.
- 5) All equipment covers are in place and secured.
- 6) There is no evidence of impending failure.

Article 130.5(B) 2: Arc Flash Risk Assessment:

The electrical equipment operating condition and condition of maintenance shall be taken in to consideration

Article 205.3 General Maintenance Requirements

- a. Electrical equipment shall be maintained in accordance with manufacturers 'instructions or industry consensus standards to reduce the risk associated with failure.
- b. The equipment owner or the owner's designated representative shall be responsible for maintenance of the electrical equipment and documentation.

Article 205.4 Overcurrent Protective Devices

Overcurrent protective devices shall be maintained in accordance with the manufacturers' instructions or industry consensus standards. Maintenance, tests, and inspections shall be documented.

Electrical equipment maintenance is not just an uptime or productivity metric anymore- Maintenance is a big part of electrical safety

