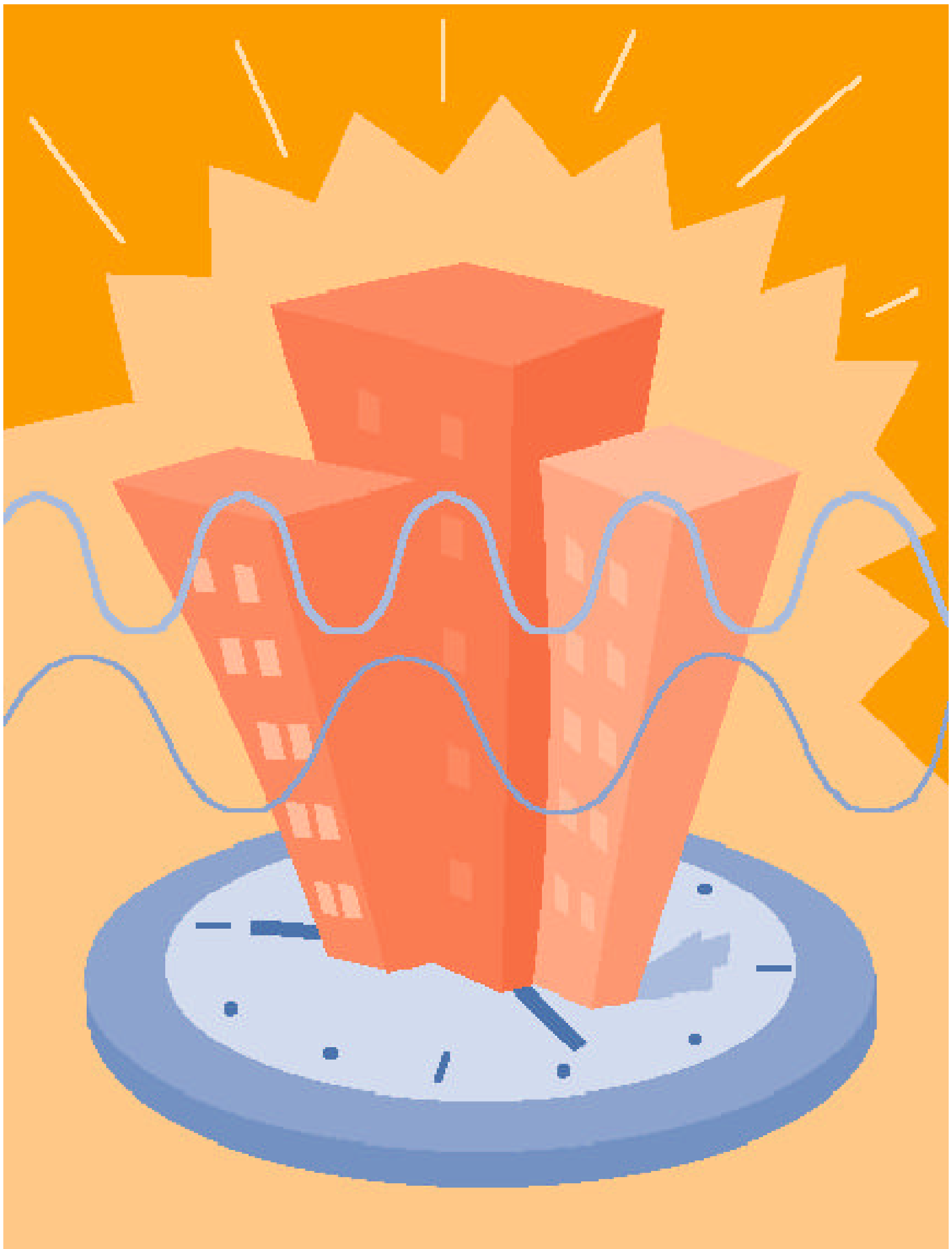
ELECTRICAL DESIGN LIBRARY

Electrical System Reliability — Inside and Out



Contents

Electrical Design Library (EDL) publications are prepared for architects, consulting engineers, and qualified electrical contractors, as well as owners, developers, investors, and their electrical construction specifying personnel. Issued periodically by the National Electrical Contractors Association (NECA), the publications provide factual explanations of the increasing variety of sophisticated electrical systems and the economics of their installation by professional electrical contractors. They are distributed by the Association's chapters, located in all sections of the United States.

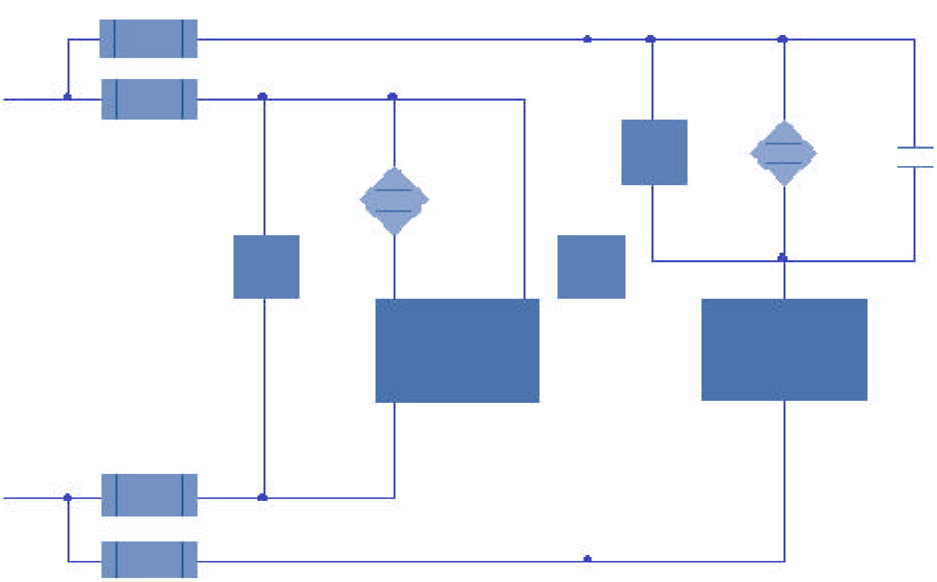
NECA acknowledges the research, writing, and production of this publication by EMR of Arlington, Virginia. In addition, the following sources used in the preparation of this document are gratefully acknowledged: National Aeronautics and Space Administration; Construction Industry Institute; Building Operating Management; and facilitiesnet.com.

Abstract

In an age in which buildings and information must to be available at all times and downtime can cost a company millions of dollars a minute, the focus on how to guarantee continuous facility uptime and power supply has never been sharper. At stake from facility failure are productivity, employee morale, and corporate credibility – all critical factors few companies can afford to take a chance on.

Today's building systems and equipment are increasingly sensitive and interrelated, making a commitment to reliability, from senior decision-makers to operation and maintenance staff, more important than ever. End-to-end reliability means that each and every component in a building, or even touching a building, must be monitored and maintained. A complementary program of predictive testing and inspection will identify problems in reliability before failure.

Even with a comprehensive reliability program incorporating the latest monitoring and testing technologies, your facility may still suffer from power outages caused by an ever increasing demand for power that is taxing utilities and causing blackouts and power disturbances. It is important to identify your facility's power needs and incorporate system backup, redundancy, or power generation alternatives to protect your business from downtime.



Introduction

On August 12, 1999, 2,300 Commonwealth Edison customers in Chicago lost electrical power after three of four transformers at a substation went off line. While one had failed a few weeks earlier, the other two failed suddenly and unexpectedly, prompting the utility to initiate a controlled outage in downtown Chicago to lighten the load on the local grid and avert a ripple effect of blown transformers throughout the city.

As a result, business in the downtown financial district that hot summer day was brought to a standstill at 1:45 p.m., with tens of thousands of office workers evacuated from darkened downtown skyscrapers. Powerless victims included banks, police headquarters, high-rise hotels, DePaul University, and the nation's largest futures market, the Chicago Board of Trade.

The utility's chairman offered no excuses, stating that the incident (the most severe in a long line of outages over the summer) was not the result of "bad luck or coincidence.... We must meet a higher level of performance," and the utility stepped up plans to overhaul its aging infrastructure.

Bringing building systems and equipment to a "higher level of performance" before a critical problem develops is an approach many facility managers and owners should also

7x24 Operations

take. Like a utility grid, a building's systems are connected to increase efficiency, but their interrelation can also make the entire building more vulnerable when a problem arises in one system or piece of equipment.

One of the best approaches to increasing the reliability of your building's systems and equipment is to develop and employ a predictive testing and inspection (PT&I) element as part of your building's maintenance program. Testing and inspection can catch potential problems in system reliability before they become problems.

In addition to taking steps in your maintenance program to ensure the reliability of your building, it is also important to develop a strategy to deal with electric power reliability failures that occur outside your facility. With demand for power in the U.S. breaking records for the third time this summer, utilities are increasingly resorting to rolling blackouts and planned outages to keep their entire systems from crashing. Typically, large industrial and commercial customers are targeted for these blackouts, and its important to be prepared with alternative power supplies and system redundancy.

One of the fastest growing trends in facilities operation and maintenance is the 7x24 facility. The Information Age has all but eliminated time zones and national boundaries, making it essential for companies in banking, investment, insurance, communications, manufacturing, and a host of other industries to conduct business seven days a week, 24 hours a day (7x24). A 7x24 facility is a mission-critical facility in which the goal is zero downtime – a building always open for business.

In a 7x24 facility, every point of failure in the building is backed up, from chillers and power generators to individual circuit breakers. Every electrical and mechanical component – from switchgear and panelboards to air handlers – is designed so that the isolation of any subsystem will not interrupt building operation. All equipment and systems are designed for optimal reliability and maintainability. Some of the key elements of 7x24 design and operation include:

- Redundancy – Incorporating duplicate critical systems into the building. 7x24 buildings are often designed with reasonable redundancy in mind, meaning the most crucial systems in the building are identified and given top priority in the company's available facilities budget so those systems have backup units that can operate in crisis situations.

- End-to-end reliability – Backing up all areas of systems (e.g., backup generators and UPS systems), and reviewing and maintaining everything that touches the facility on a regular basis.

- Concurrent maintenance – Building a system that can be taken offline for maintenance during normal business hours without disrupting the facility's operations. Each piece of equipment, subsystem, and system must be configured to be taken off-line, serviced, and restored to operation without risk of interruption.

- Commissioning – Testing all elements of a building (from components to installed systems) to ensure everything works properly, and training O&M staff and technicians to thoroughly maintain equipment and systems. The building's systems must be factory- and site-tested for individual performance and integration.

Determining the Needs of your Facility

Another vital element to a successful 7x24 facility is projecting future requirements – for everything from computer processing to networking and telecommunications to furniture and space planning – and making these projected requirements part of all design and construction plans for the facility.

While the 7x24 operations approach is becoming more popular, many businesses do not need such a radical approach to improving the reliability of their equipment, systems, power sources, and overall facility. The first factor to consider is the financial consequences of downtime. All companies lose money when mission-critical equipment fails, but in the event of a power outage, an investment firm offering online trading stands to lose millions more per minute than a small company that doesn't offer e-commerce. The online investment firm should seriously consider 7x24 operations, while the small company might just provide its employees with surge protectors for their workstations.

What are the most frequent causes of power failures in the facility another vital consideration. Have overloaded power lines during the summer months caused your utility to schedule rolling blackouts? Backup power sources may be the answer. Does your system experience recurring power quality problems (e.g., voltage swells, voltage sags, ripples, over- or undervoltages, harmonics, etc.)? Then UPS and power conditioning approaches may suffice. Are the power failures from secondary power quality problems generated by other in-house equipment? Then a comprehensive reliability centered maintenance program that includes predictive testing and inspection may be necessary.

7x24 Operations – How to Eliminate Downtime

Adhering to these stringent uptime requirements for a 7x24 facility can all but eliminate downtime in your facility:

- *Fifth Sigma/99.999% uptime reliability (315 seconds, or a little more than five minutes, of outage per year).*
- *All maintenance is performed with facility online and processing underway.*
- *No facility shutdowns are allowed under any circumstances.*
- *All systems are provided with redundant enterprise-level MEP system movers and primary/secondary distribution.*
- *All raised floor equipment is dual cord set or dual fed.*
- *UPS bypass power goes to another UPS source.*
- *The facility is on a dedicated utility feeder.*
- *Maintenance is performed on redundant, enterprise-level MDP systems and units only during periods of lower processing load. No other major maintenance or testing should occur at this time.*
- *Maintenance is performed on redundant distribution systems only when there is no work being performed on any other portion of the attendant system.*
- *Only one unit or system component receives maintenance at any given time.*

Source: Building Operating Management, February 1998 .

In general, the following process should be used not only to determine the reliability requirements of your facility, but to address power quality and reliability issues as well:

- Develop a Power Strategy – Evaluate the power requirements of your facility. Develop an electric load profile that summarizes electrical energy consumption and demand over 24 hours, power quality, and electric power reliability requirements. Isolate mission-critical electrical loads when analyzing your power procurement options; these loads should be evaluated in terms of reliability, not potential cost savings.

- Perform a Risk Analysis on Mission-critical Equipment – Record each power quality event, fault, and disturbance, both internal and external. Predictive testing and inspection is often the most thorough method for locating power and equipment failures. Rank each event, fault, or disturbance according to its impact on mission-critical performance, and decide the allowable tolerance level. Keep in mind that a risk assessment looks at the frequency or possibility that an event or fault will occur and its subsequent effect on operations.

- Negotiate with Utilities and Other Power Providers – Use the information gathered in the facility electric load profile to negotiate with electricity providers. Negotiating with utilities and other electricity providers is a good business move irrespective of the

Standby Power Keeps the Data Flowing for Acxiom

Located on a sprawling campus in Conway, Arkansas, Acxiom Corporation specializes in storing, streamlining and upgrading proprietary data for insurance companies and credit agencies. The company's specialty is data warehousing, including real-time data processing and other information storage services, so it's critical that Acxiom is on-line 24 hours a day, seven days a week.

Because Conway serves as a small distribution center for Arkansas Power & Light, Acxiom is very susceptible to power bumps, making reliable emergency power for its computer facilities essential. Though the surges or sags last no more than one or two seconds, they would crash the company's computers without reliable standby power.

That power is supplied by seven standby generator sets strategically placed throughout the campus. Acxiom specified its first equipment, three Caterpillar 3512 gensets, rated at 1,000 kW each, about six years ago. The units were paralleled off one soft-load transfer switch to handle the company's emergency power needs. Two Cat 3516 gensets; rated at 1,750 kW, three years ago, followed by two more Cat 3512s, each 1,000 kW, two years later. Each of our four newest gensets is a stand-alone system with its own automatic transfer switch (ATS).

Computers are Acxiom's lifeline, and the gensets protect the environment in which the computers operate, especially the critical air conditioning. Acxiom's computers are connected to a system of trickle-charge UPS batteries. The batteries are always on-line; if there's a dip in power as brief as three milliseconds, the switch to UPS is seamless.

As new clients are added and data processing needs grow, Acxiom adds standby gensets to accept the increased load, ensuring that the company will always be "online" for its clients.

Source: Powerline/Riggs Power Systems

status of electric utility deregulation in your state. Negotiate not only for better rates and more stable pricing over time, but also for better power quality. Consider distributed or self-generation options to counteract planned blackouts.

- Explore Ways to Cut Energy Use and Reduce Demand – Implement energy efficiency measures in non-critical areas such as offices and restrooms. To provide flexibility for shifting loads, consider designing separate cooling schemes for critical and non-critical areas. Consider using thermal capacity storage, fuel cells, or other distributed generation technologies to reduce demand during periods of peak usage. Electricity demand can also be reduced using alternate fuels (e.g., steam or natural gas).

After the power source reliability has been addressed, your facility is ready for a reliability centered maintenance program that incorporates predictive testing and inspection to address reliability problems that are generated internally and not the result of blackouts or poor power quality from your power provider.

Developing a Corporate Commitment to Reliability

Though the amount of thought and consideration that goes into the design, procurement, testing, and maintenance of a reliable facility may seem daunting, these tasks often pale in comparison to selling senior reliability program. All of the system redundancy and backup, as well as monitoring and testing, that goes into a highly reliable facility means a higher facilities O&M budget. Qualified contractors in sensitive facility equipment and electronics may not be the least expensive. It is important to stress to corporate decision-makers the importance of value over cost when it comes to facility reliability and uptime.

Before a company undertakes a reliability program, management and facilities staff alike must determine the facility's life expectancy and required reliability. Consider the following questions:

- What is the impact of system failures on mission-critical equipment and overall facility operations? How severe are the financial consequences?
- What are the most frequent causes of power failures in the facility (e.g., weather, overloaded power lines, etc.)?
- Does the system suffer from recurring power quality problems (e.g., voltage swells, voltage sags, ripples, over- or undervoltages, harmonics, etc.)?
- Are the power failures from secondary power quality problems generated by other in-house equipment?

The answers to these questions will help guide corporate decision makers in determining how much reliability is required, how much business is being affected by current problems in reliability, and how much risk the business can afford to take.

The Construction Industry Institute, Design for Maintainability Research Team has developed six vital steps to take to developing a successful plan for facility and systems reliability and maintainability:

Step 1 - Obtain Corporate Commitment

The catalyst for implementing maintainability is an overall, corporate commitment to develop and follow a formal process to institutionalize maintainability throughout the organization. Justifying a comprehensive commitment to reliability to senior management requires research, information gathering and a thorough understanding of how the mission-critical components of a facility interact with the business.

Maintaining Reliability

Step 2 - Establish a Corporate Level Program

This is a straightforward process involving a commitment of both human and financial resources to achieve a consistent process of implementation using standard procedures throughout the organization. Facilities management must be considered as seriously as sales, accounting, and other functions of the company.

Step 3 - Obtain Reliability and Maintainability Capabilities

This step moves from the central or corporate level of the business to a more local or project level, becoming directly tied into the project delivery process. Reaching this milestone means that the project is enabled to support and implement design for maintainability. It also means an evaluation of in-house O&M staff and technicians is necessary – identify training and staffing requirements.

Step 4 – Develop a Program Implementation Plan

This step occurs when the resources are committed and the process is enabled. A cross-functional project team with resident reliability expertise should be formed. This project team identifies the reliability needs of the facility and the business, develops the maintenance strategy, develops project maintainability objectives, and considers appropriate technologies to integrate into the project design.

Step 5 - Implement Reliability and Maintainability

This step occurs when all the elements are in place to fully implement maintainability. Within this step are the best practices that actually implement maintainability on all phases of the project – design, procurement, construction, start-up, and review. Technologies and approaches to maintain reliability are applied to the design, considered during procurement, recognized during construction, taught during owner/staff training, and evaluated at project conclusion.

Step 6 - Update the Corporate Level Program

The critical element that distinguishes the ideal process is establishing the feedback mechanism as a driver for continuously improving the reliability process. This is the last step in implementing the corporate level maintainability program, and should include integrating the goals of the reliability program into the company's long-term plan.

Reliability centered maintenance (RCM) is a continuous process to find the optimum mix of reactive, preventive, predictive, and proactive maintenance practices that will achieve the required reliability at the lowest cost. The maintenance strategies, each of which has its own strengths, are integrated to optimize facility and equipment reliability.

RCM's goals are to determine for each system and equipment the failure modes and their consequences, and to identify the most cost-effective and applicable maintenance technique to reduce the risk and consequences of failure. Specific RCM objectives are:

- To truly understand the safety and reliability levels of the equipment.
- To restore the equipment to these levels when deterioration occurs.
- To correct those items in which reliability is inadequate.
- To achieve these goals at a minimum total cost, including maintenance costs, support costs, and the costs of operational failures.

The goal of RCM is to enhance equipment reliability, primarily by getting maintenance experience and equipment condition data to facility planners, designers, maintenance managers, craftsmen, and manufacturers. This information, which is essential to improving equipment specifications, will continually increase reliability and decrease the occurrence of equipment failures, resulting in greater availability for mission support and lower maintenance costs.

The start-up costs needed to acquire the technological tools, training, and equipment condition baselines for a new RCM program usually results in a short-term increase in maintenance costs. This short-lived spike drops quickly as the cost of reactive maintenance decreases, as failures are prevented, and as preventive maintenance tasks are replaced by condition monitoring.

An RCM program achieves maximum use from equipment and systems that is based on condition on is not reliant on scheduled maintenance tasks. This condition-based approach to maintenance lengthens facility and equipment life.

Reliability and the Facility Life Cycle

To achieve maximum effectiveness, reliability must be integrated into the life cycle at an early stage, and should be a consideration throughout the life cycle (planning, design, construction, and operation and maintenance).

Decisions made early in the facility life cycle have a significant affect on a facility's reliability and costs. The decision to commit to an RCM program, including PT&I and condition monitoring is best made during the planning phase. When RCM decisions are made later in the life cycle, it becomes more difficult to achieve the maximum possible benefit from the RCM program.

Even though maintenance is a relatively small portion of the overall life-cycle cost (typically three to five percent of a facility's operating cost), a reliability program is still capable of introducing significant savings during the maintenance and operations phase of the facility's life. Savings of 30% to 50% in the annual maintenance budget are often obtained through the introduction of a balanced RCM program.

RCM Analysis

For RCM to be effective, maintenance decisions are made based on maintenance requirements, backed by sensible technical and economic rationale. The successful practice of RCM requires a careful analysis of the following questions:

- What does the system or equipment do?
- What functional failures are likely to occur?
- What are the likely consequences of these functional failures?
- What can be done to prevent these functional failures?

Functional failures occur when a system or subsystem fails to meet its functional requirements. However, a system or subsystem that is operating in a degraded state but does not have a substantial impact on system components has not experienced a functional failure.

It is critical to look at all of the significant operational functions of an item so that functional failure for that item can be properly defined. A case in point is aircraft brakes. The brakes not only stop the plane, but they also provide braking for maneuvering, modulated stopping, and anti-skid capability. Therefore, the prevention of potential failures averts functional failures. The purpose of PT&I is to find and quantify degradations that indicate the presence of potential failures.

In this context, reliability is defined as the likelihood that an item will perform without failure during a given operating period, under specified operating conditions. Every equipment item has a characteristic that is called margin to failure. The use of equipment causes stress, which can result in failure when the stress exceeds the resistance to failure. Reliability can be increased (i.e., failures can be prevented) by:

- Decreasing the amount of stress applied to the item.

What Defines a Reliability Centered Maintenance Program?

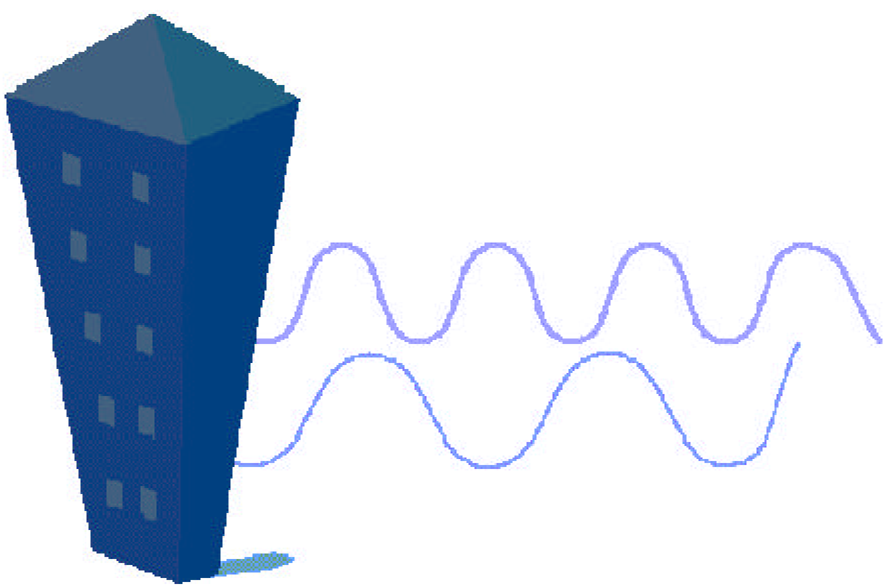
- *Orientation on Function – the approach seeks to preserve system or equipment function, not just operability for operability's sake. Redundancy of function through multiple equipment improves functional reliability, but increases life cycle cost.*
- *Focus on Systems – RCM is more concerned with maintaining system function than component function.*
- *Central Focus on Reliability – the approach treats failure statistics in an actuarial manner. The relationship between operating age and the failures experienced is important. RCM is not overly concerned with simple failure rate; it seeks to know the conditional probability of failure at specific ages (the probability that failure will occur in each given operating age bracket).*
- *Acknowledgment of Design Limitations – the objective is to maintain the inherent reliability of the equipment design, recognizing that changes in inherent reliability are the province of design rather than maintenance. Maintenance can, at best, only achieve and maintain the level of reliability for equipment that is provided by design. However, RCM recognizes that maintenance feedback can improve on the original design. RCM recognizes that a difference often exists between the perceived design life and the intrinsic or actual design life.*
- *Driven by Safety and Economics – safety must be ensured at any cost; cost-effectiveness is the criterion.*
- *Definition of Failure as Any Unsatisfactory Condition – therefore, failure may be either a loss of function (operation ceases) or a loss of acceptable quality (operation continues).*
- *A Logic Tree Screens Maintenance Tasks – this provides a consistent approach to the maintenance of all kinds of equipment (see Figure 1 on page 10).*
- *Tasks Must Be Effective – the tasks must be technically sound and cost effective.*
- *Tasks Must Be Applicable – the tasks must reduce the number of failures or ameliorate secondary damage resulting from failure and be cost effective.*
- *Acknowledgment of Three Types of Maintenance Tasks and Run-to-Failure – these tasks are time-directed (preventive), condition-directed (predictive), and failure-finding (proactive). Time-directed tasks are scheduled when appropriate. Condition-directed tasks are performed when conditions indicate they are needed. Failure-finding tasks detect hidden functions which have failed without giving evidence of pending failure. In RCM, run-to-failure is a conscious decision.*
- *Emphasis on the Living System – RCM gathers data from the results achieved and feeds this data back to improve design and future maintenance. This feedback is an important part of the proactive maintenance element of the RCM program.*

Source: NASA Reliability-Centered Maintenance Guidebook

Predictive Testing and Inspection

- Increasing or restoring the item's resistance to failure.
- Decreasing the rate of degradation of the item's resistance to or margin to failure.

How much stress that occurs depends on use and may be highly variable. It may increase, decrease, or remain constant with use or time. A review of the failures of a large number of reasonably identical simple items would reveal that the majority was approximately the same age at failure (subject to statistical variation) and that these failures occurred for the same reason. Therefore, by finding a way to measure a simple item's resistance to failure, it is possible to select an approach to prevent, and thus improve reliability.



Predictive testing and inspection (PT&I) is the use of advanced technology to evaluate equipment condition, with the goal being to predict and fix problems before they occur. PT&I data collected provides a baseline of system and equipment performance, and is used to plan and schedule preventive maintenance or repairs before equipment failure occurs (all of which increases reliability). In the commercial building industry, PT&I is sometimes called condition monitoring, or predictive maintenance. Condition-based maintenance is the work done as a result of PT&I data analysis.

As the predictive maintenance field continues to grow, new and more economical technologies are being developed. The technologies identified below are not the only testing technologies available. However, they are reasonable and cost-effective approaches for most facilities and collateral equipment. Some are directly related to a facility's electrical distribution system and power quality; all are important to a reliable facility and systems performance.

Full Disclosure Power Monitoring – A recent breakthrough in PT&I technology is the use of full disclosure power monitors that use digital signal processing and high-speed sampling to capture data on power disturbances, harmonics, flicker, and consumption. Full disclosure power monitors analyze even the smallest event, exposing degradation in the electrical distribution system of a facility (and thus predicting system failure).

Infrared Thermography (IRT) - IRT is a non-contact, line-of-sight, thermal measurement and imaging test that identifies temperature differences. It is ideal for finding hot/cold spots in energized electrical equipment, large surface areas such as roofs and building walls, and other areas where "stand off" temperature measurement is necessary.

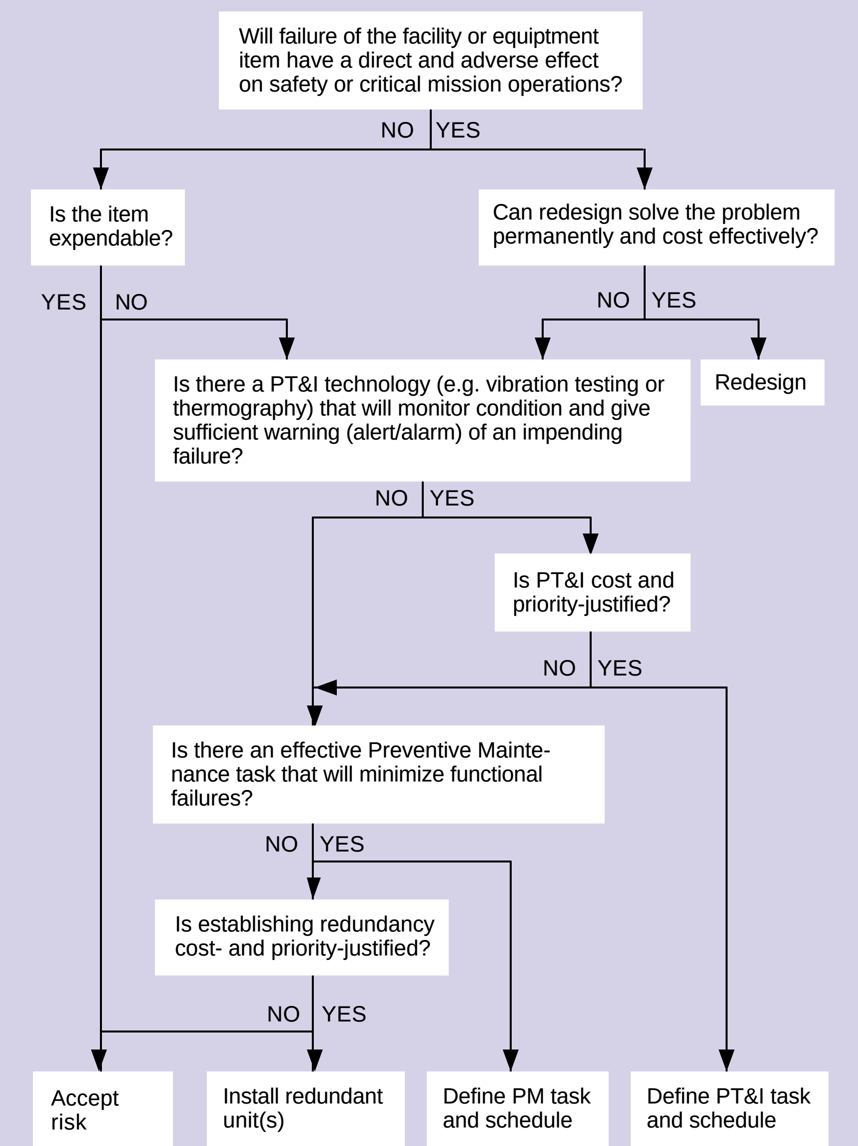
IRT inspections are either qualitative or quantitative. The quantitative inspection offers an accurate measurement of the temperature of the item of interest. The qualitative inspection identifies relative differences, hot/cold spots, and deviations from normal or expected temperature ranges, producing highly accurate temperature differences between similar components.

IRT can be used to locate improper installation conditions in electrical systems such as transformers, motor control centers, switchgear, switchyards, or power lines. In mechanical systems, IRT can determine blocked flow conditions in heat exchanges, condensers, transformer cooling radiators, and pipes.

Insulation Power Factor Test – Insulation power factor, sometimes called dissipation factor, is the measure of the power loss through an insulation system to ground. It is a dimensionless ratio that is expressed as a percent of the resistive current flowing through the insulation to the total current flowing. To measure this value, a known voltage is applied to the insulation and the resulting current and current/voltage phase relationship is measured. The results are measured in milliwatts lost. This non-destructive test will not deteriorate or damage insulation and is considered one of the best electrical PT&I tests.

Motor Circuit Analysis – Motor circuit analysis is an off-line motor technology that monitors the condition of the complete motor circuit. The test device measures the basic electrical characteristics, phase resistance, phase inductance, resistance to ground, and capacitance to ground, that comprise all motor circuits. The test equipment is portable and computer-based, which allows for automated test performance and data collection.

Figure 1, RCM Logic Tree



Motor Current Signature Analysis – Developed by Oak Ridge National Laboratory, this technique tests a variety of motor-driven components in general industrial applications. The approach makes use of the fact that an electrical motor is a reliable transducer of mechanically induced loads. It uses these loads to modulate the motor line current signal flowing through the motor stator windings. (Roger Carr, P/PM Technology, Volume 8, Issue 3, June 1995, p. 50).

Electrical Signal Analysis – Electrical signal analysis is an on-line diagnostic technology that evaluates the condition of a motor circuit. Data collected includes voltage and current balance, power quality, impedance balance, and current sequence data.

Vibration Monitoring – This technique involves measuring machinery movement, or vibration, to identify ongoing conditions through the use of an accelerometer. It also examines the vibration spectrum to identify and trend frequencies of interest. Some frequencies correlate to machine design, regardless of equipment condition. For example, a healthy fan or rotary compressor may have a frequency that is equal to the machine speed times the number of fan blades. Monitoring this frequency and noting changes in the amplitude indicate whether there is a degrading condition.

Other frequencies, such as those associated with rolling element bearings, may be a sign of bearing damage. Electric motor problems, such as broken rotor bars or stator eccentricity, are commonly seen in vibration signatures associated with electrical line frequency. Vibration analysis is very helpful in identifying faulty bearings and verifying proper alignment and balance of new equipment.

Airborne Ultrasonic Test – An ultrasonic noise detector, a fairly inexpensive tool, can be used to find liquid and gas (pressure and vacuum) leaks. When a fluid or gas moves from a high-pressure region to a low-pressure region, ultrasonic noise is emitted. The detector translates the ultrasonic noise to the audible range. An ultrasonic noise detector is also useful in locating arcing, tracking, and corona in electrical systems. The detector is used in conjunction with an IRT inspection.

Dissolved Gas Analysis – A 50cc sample of oil from an oil-filled transformer is examined for dissolved gases using gas chromatography. This test is very effective at uncovering the problems associated with an oil-filled transformer before the problem becomes terminal.

Lubricating Oil Test – An oil analysis verifies that the specified lubricants are being used and that the system is free of construction contamination. In an operating system, lubricating oil analysis is performed to determine the machine mechanical wear condition, to determine the lubricant condition, and to determine if the lubricant has become contaminated.

Insulating Oil Test – Similar to a lubricating oil analysis, testing is performed to verify that the specified oil is used. The tests include Karl Fischer (water in oil), acidity level (neutralization number), interfacial tension, and electrical dielectric.

Battery Impedance Test – All batteries have a storage capacity that is dependent on the terminal voltage and internal impedance. A battery impedance test set injects an AC signal between the terminals of the battery. The resulting voltage is measured and the impedance is then calculated. Two comparisons are made: first, the impedance is compared with the last reading for that battery, and second, the reading is compared with other batteries in the same bank. Each battery should be within 10 percent of the others and 5 percent of its last reading. A reading outside of these values indicates a cell problem or capacity loss.

Insulation Resistance Test – An insulation resistance test is a nondestructive DC test used to determine insulation resistance to ground. A DC voltage is applied to the equipment being tested and a small current flow results. The test set, which then calculates the resistance, is a reliable gauge for the presence of contamination or degradation.

Flux Analysis – The flux analysis technique involves measuring and analyzing the magnetic leakage flux field around a motor. Designed to detect faults in rotor bars, stator turn-to-turn shorts, and phase-to-phase faults, this technique is similar to that of motor current signature analysis.

Ultrasonic Mapping – Used to help identify wet insulation in roofs, an ultrasonic signal is sent through the roof surface and reflections are measured. A strong reflection indicates the potential of wet insulation. Most ultrasonic mapping detectors are small units with wheels, and a complete inspection requires walking the unit across the entire surface of the roof.

Go/No-Go Tests

PT&I testing typically provides data suitable for long-term monitoring and trends analysis. Listed below are equally helpful tests that do not provide data that can be used for trending; in these tests, either the equipment passes the test or it does not.

High Potential Test – Hi-Pot testing is a DC high voltage test that is used to show excessive leakage current in in-service equipment and to verify that insulation systems in new equipment can withstand designed voltage levels. As a result, it serves as an effective acceptance test for new and repaired electrical transmission and distribution equipment. For example, in repaired equipment, if leakage current continues to increase at a constant test voltage this indicates that the repair is not up to the proper standard and will probably fail soon. In new equipment, if the equipment does not withstand the appropriate test voltage it indicates the insulation system or construction method is inadequate for long term service reliability. Since DC Hi-Pot testing is a potentially destructive test, it typically is not used in a PT&I program.

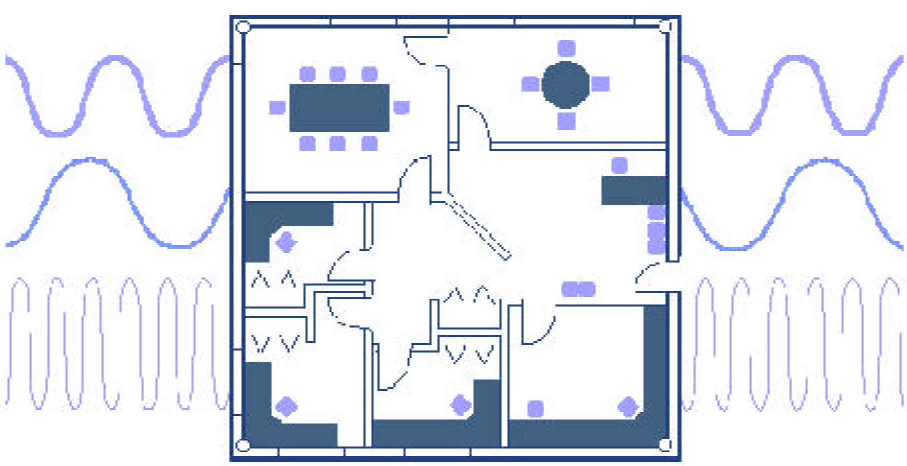
Turns Ratio Test (TTR) – Mainly used as an acceptance test, TTR measures the turns-ratio of a transformer, including identifying short-circuited turns, incorrect tap settings, mislabeled terminals, and failure in tap changers. To run a turns-ratio test, a voltage is sent to the primary, and the induced voltage on the secondary is measured. The ratio is then calculated and compared with the nameplate data. A turns-ratio measurement can show that a fault exists, but it cannot determine the reason or location of the fault. TTR also can be used as a troubleshooting tool when other electrical tests turn up possible problem.

Partial Discharge Analysis (PD) – This is an on-line technology that monitors the condition of insulation in machines and cables above 4,000VAC. A partial discharge is an incomplete, or partial, electrical discharge that occurs between an electrical item's own insulation, between an electrical item's own insulation and other insulation, or between insulation and a conductor. These discharges create a high-frequency signal that PD monitoring systems detect.

Breaker Timing Test – This mechanical test shows the speed and position of breaker contacts before, during, and after operation. Two general types of timers are used: digital contact timers and digital contact and breaker travel analyzers.

A digital contact timer is used only for timing contacts where no travel time is required. A digital contact and breaker analyzer measures contact velocity, travel, overtravel, bounce back, and acceleration to assess the condition of the breaker operating mechanism. A voltage is applied to the breaker contacts, and a motion transducer is attached to the operating mechanism. The breaker is then closed and opened, and the test set measures the timeframe of voltage changes and plots the voltage changes over the motion waveform produced by the motion transducer. The numbers are printed out from the test set, and the chart is stored in memory for downloading to a computer.

Flow/Pressure Test – Many facility systems are closed loop-type systems and any pressure or vacuum leaks are not allowable. To verify that the system was designed and installed properly, actual flow rates of liquids or gases are measured and compared with the design criteria. Additionally, leak tests are performed to confirm system integrity.



Reliability Issues Today and Beyond

Several factors will have an increasingly important impact on the reliability and maintainability of a facility and its electric power supply as we head into the new millenium. These factors include the continuing rollout of electric utility deregulation, anticipating tomorrow's business technologies, and training O&M staff and technicians to service increasingly complex and critical systems.

The deregulation of power generation presents many opportunities for businesses. However, in addition to using deregulation to negotiate for better rates and stabilized power costs, facility managers must also keep in mind their service requirements. For any business reliant on facility uptime, the cost of electricity is not as important as its quality and reliability. When considering proposals from the range of utility providers, energy service companies, power marketers, etc., make reliable service your first priority.

As computer processors become smaller and faster (a trend that will undoubtedly continue), they become more sensitive to power fluctuations. Small voltage changes can cause major problems, even system-wide crashes. Consider installing UPS systems to guard against power sags and surges, and utilizing self-generation in the form of fuel cells or backup generators to guarantee continuous power (see Distributed Generation – Supplementing Your Power Supply on page 14. Newer computer equipment can be equipped with dual power paths – one path might be from the utility source, while the second may be connected to an alternate utility line or a backup power system.

Planning for future requirements in facility construction and design is also important. Your facility should be able to accommodate technologies that do not yet exist, and power requirements you cannot yet imagine. As much as possible, keep wiring, piping, conduits, and raised flooring expandable and flexible. Space, piping, conduits, etc. for mechanical systems, such as chillers and air handlers, should also be considered for their expandability to handle increasing loads.

Finally, as more companies realize the importance of facility and system reliability, finding facilities maintenance staff qualified and knowledgeable in all of the complex aspects of reliability is a challenge. NECA contractors are at an advantage because they can offer many of the specialized services (listed below) that ensure reliability in electrical systems, power supply, and the overall facility and its equipment. Also, consider partnering with other qualified contractors to provide a full package of services in the reliability arena.

- Reliability problems troubleshooting
- Power-sourcing strategies
- Economic evaluation/financing
- Mechanical and electrical engineering (particularly an emphasis in data center design)
- Building commissioning
- Construction
- Reliability-centered maintenance (RCM)
- Predictive testing and inspection (PT&I)
- Self-generation alternatives
- Back-up power alternatives
- Power monitoring

Distributed Generation - Supplementing Power Supply

Facility managers interested in supplementing their supply of power should investigate opportunities in distributed generation and self-generation. Distributed generation is the integrated or stand-alone use of modular generation resources, used by utilities and third-party providers in applications that benefit the electric system, specific customers, or both. Self-generation is the use of the same generation resources, only by the facility that plans to use the power. With both distributed and self-generation, excess power supply produced can be sold back to the utility.

Distributed and self-generation encompass a broad range of technologies and load requirements (typically from 25kW to 25MW). Formerly used for large industrial systems and medical facilities, the latest distributed generation systems are smaller and more economical to install and use. Typical return on investment ranges from 15 to 25 percent.

Many facilities that require 7x24 operations use some form of on-site generation to provide redundancy in their power supply. For instance, redundancy is built into Internet Service Provider America Online's power distribution system at its data center near Washington, D.C. The center can operate fully from either of two separate 34.5 kV utility services. In addition, six 1,600 kW engine-generators are on hand for emergency backup power, with space available for two more. The system even includes three individual UPS systems to back up the engine-generators and provide power conditioning. The redundancy is vital considering the importance to AOL of availability to its customers, on demand, at any time.

Following is a brief discussion of the most types of generation technologies commonly used by facilities today.

Microturbine Generators

Microturbine generators are heat engines that use high-temperature, high pressure gas as the working fluid. Part of the heat supplied by the gas is converted directly into the mechanical work of rotation. In most cases, the hot gases for operating a gas turbine are obtained by the combustion of a fuel in air, which is why gas turbines are often referred to as combustion turbines.

Because they are compact, lightweight, and easy to operate, microturbine generators have found many applications, notably the generation of electricity and steam (many industrial processes require steam in addition to electricity). The natural gas used to power the microturbine generator can be one-third to one-seventh the cost of utility-provided electricity.

The new class of microturbines consist of a compressor, combustor, turbine, and generator. They are typically less than 300 kw (400 hp) in total power output and use low nitrogen oxide (NO_x) emission that are well within the limits of the most stringent regulations, both current and proposed. They have few moving parts, require little maintenance and no liquid cooling. They also are quiet, compact, and in some cases lightweight.

Photovoltaic Systems

Photovoltaic (PV) systems convert solar energy into electricity and are commonly known as solar cells. PV systems provide power for anything from small calculators and wrist watches to complex systems providing electricity for pumping water, powering communications equipment and even lighting homes and running appliances. The system works when a PV cell converts sunlight, which is made of photons, or particles of solar energy, into electricity.

One solar cells typically produces between 1 and 2 watts. Cells are connected together to form larger units called modules, and modules are be connected to form even larger units called arrays, which can be interconnected for more power.

PV-generated power offers advantages over diesel generators, primary (one-time use) batteries, and even conventional utility power. Highly reliable, with low construction and operating costs, PV systems are highly customizable and mobile, and they are clean and silent. PV systems can be connected to a battery, and the battery to a load. During daylight hours, the PV modules charge the battery and the battery supplies power to the load whenever needed. A charge controller protects them from overcharging or draining.

Fuel Cells

Fuel cells provide a way of generating electricity without combustion and without air or water pollution. Like batteries, they convert chemical energy in a fuel, such as methane or methanol, directly into electricity. Also like batteries, they have positive and negative electrodes and an electrolyte. Fuel cells, however can operate continuously as long as fuel and air are supplied, unlike a battery, which can provide power for a limited time before requiring recharging or replacement. To generate a useful amount of current, fuel cells are stacked in multilayers.

Fuel cells are efficient, with over 40 percent of the energy in the fuel converted directly into electricity. When used in distributed generation applications, over 80 percent of the energy in the fuel is available as useful heat and electricity. Fuel cells can produce greater value from the natural gas consumed than any other type of power generation system.

In comparison to traditional combustion methods of generating electricity, fuel cells offer several advantages. Since no combustion is involved, a fuel cell operating on hydrogen and oxygen produces no NO_x or carbon dioxide (CO_2) emissions. Other fuels, such as natural gas and methanol produce emissions well below all current environmental standards.

Fuel cells contain no moving parts and are, therefore, low in noise and vibration. Similar to PV systems, fuel cell systems are modular and scaleable. A typical fuel cell consists of four major components: a fuel processor, fuel cell stack, power conditioning system, and energy recovery system. The fuel processor converts a hydrocarbon fuel into hydrogen gas. The fuel cell stack combines the hydrogen with oxygen to produce DC power. The power conditioning system converts the DC power into AC or DC power with the proper voltage and frequency. The energy recovery system uses the excess heat energy for distributed generation functions.

Fuel cells are an emerging technology, and while they are gaining fast in commercial viability, they should be considered a supplemental power source option only when economically feasible.

EDL ORDER FORM

The following monographs are $3.00 each for NECA members, $5.00 for utilities, and $10.00 for others. Prices for bulk quantities will be quoted upon request.

	Date	Title	Index No.
❑	4/92	Effective Lighting Controls for Modern Buildings	302575
❑	8/92	Electro-Technologies for Intelligent Buildings	302576
❑	12/92	Design to Improve Power Quality	302577
❑	4/93	Benefits of Adjustable Speed Drives	302578
❑	8/93	Electro-Technologies for Waste Management	302579
❑	12/93	Getting Ahead in Network Communications	302580
❑	6/94	Distributed Intelligence Control Networks	302581
❑	9/94	Fiber Optic Cable Paves The Information Highway	302582
❑	12/94	The Electronic Butler	302583
❑	6/95	Electrotechnologies for Wastewater Management	302584
❑	9/95	Performance Contracting—An Innovative Financing Option	302585
❑	12/95	Reliability Centered Maintenance—A Cost-Effective Solution for Facilities Maintenance	302586
❑	4/96	Demand-Side Management Transformation	302587
❑	8/96	Heat Pump Technology	302588
❑	12/96	Building Commissioning	302589
❑	4/97	Intelligent Building Control Networks	302590
❑	8/97	Advances in Electrotechnologies	302591
❑	12/97	Utility Deregulation and the Facility Manager	302592
❑	4/98	Power Quality	302593
❑	8/98	Advanced Meter Reading Technologies	302594
❑	12/98	Distributed Power Generation Technologies	302595
❑	4/99	Task-Driven Lighting	302596
❑	8/99	Energy Savings Performance Contracting—A New Frontier	302597
❑	12/99	Electrical System Reliability—Inside and Out	302598
❑	____	Complete set of EDL publications (3025SER) available for $35 for NECA members or $70 for nonmembers.	

Please send me the EDL(s) that I have checked above. A check in the amount of $ ________________________________
for ___________________________ copies is enclosed.

Name ____

Address ____

City ______________________________________ State ____________________Zip ____________________

Please mail this EDL order form and your check (made payable to NECA) to:
National Electrical Contractors Association, 3 Bethesda Metro Center, Suite 1100, Bethesda, MD 20814–5372.

NECA Chapter Locations

The National Electrical Contractors Association, Inc., was founded in 1901. It represents the electrical contracting industry and is organized into independent, local chapters throughout the United States, Australia, Canada, Mexico and New Zealand. The headquarters office is located at 3 Bethesda Metro Center, Suite 1100, Bethesda, MD 20814–5372. Field service regional offices are located in Covington, LA, Schaumburg, IL, Syracuse, NY, and Oakland, CA. For help in locating a qualified electrical contractor in your area or for more information concerning this publication, contact the NECA Chapter Office nearest you.

ALABAMA : Mobile (334/479-9534)
ALASKA: Anchorage (907/561-1958)
ARIZONA: Phoenix (602/263-0111), Tucson (520/323-1622)
ARKANSAS: Little Rock (501/758-2224)
CALIFORNIA: Santa Maria (805/348-1200), Martinez (925/372-3222), Fresno (559/230-0990), Bakersfield (661/325-5937), Los Angeles (213/487-7313), Salinas (805/348-1200), Oakland (925/737-0460), Orange (714/634-8777), Petaluma (707/765-1050), San Diego (619/298-1183), San Francisco (415/703-8333), Stockton (209/478-8105), Redwood City (650/364-8100), San Jose (408/288-6100), San Bernardino (909/824-7050), Sacramento (916/376-8980)
COLORADO: Denver (303/937-3900), Colorado Springs (719/636-3901)
CONNECTICUT: Milford (203/287-1444)
DELAWARE: Philadelphia, PA (215/732-1444)
DISTRICT OF COLUMBIA: Annandale, VA (703/658-4383)
FLORIDA: Orlando (407/426-9050), Tampa (813/253-0887), Jacksonville (904/633-9448), Miami (305/828-9918)
GEORGIA: Atlanta (770/454-6400), Augusta (706/262-6322), Savannah (912/355-1252), Atlanta [Southeastern Line Constructors] (770/969-9209)
HAWAII: Contact NECA Marketing Services in Bethesda, MD (301/215-4525)
IDAHO: Boise (208/322-4744)
ILLINOIS: Peoria (309/673-6900), Chicago (708/531-0022), Joliet (815/729-2288), Springfield (217/787-9500), Northeastern Illinois (630/876-5360), Rockford (815/874-8400), Quad Cities (319/322-5371)
INDIANA: Indianapolis (317/846-5680), Michigan City (219/872-3151), Evansville (812/422-3259)
IOWA: Des Moines (515/278-2341)
KANSAS: 316/265-7067
KENTUCKY: Louisville (502/893-2713)
LOUISIANA: Baton Rouge (225/752-7970), Shreveport (318/458-6674), Monroe (318/387-4411), New Orleans (504/733-9370), Lake Charles (318/436-0886)
MAINE: Boston, MA (617/969-2521
MARYLAND: Baltimore (410/727-1645)
MASSACHUSETTS: Boston (617/969-2521), Worcester (508/752-6422), Springfield (413/785-1337)
MICHIGAN: Lansing (517/372-3080), Detroit (248/355-3500)
MINNESOTA: Minneapolis (612/591-1800), St. Paul (651/224-3377), Duluth (218/722-8115)
MISSISSIPPI: Jackson (601/373-1623)
MISSOURI: Kansas City (816/753-7444), Kansas City [Southwestern Line Constructors] (816/891-8570), Kansas City [Missouri Valley Line Constructors] (816/891-9066), St. Louis (314/644-3030)
MONTANA: Helena (406/442-8330)
NEBRASKA: Omaha (402/397-5105)
NEVADA: Las Vegas (702/876-7860)
NEW HAMPSHIRE: Boston, MA (617/969-2521
NEW JERSEY: Mountainside (908/654-5770), Mt. Laurel (856/722-6777)
NEW MEXICO: Albuquerque (505/883-6677)
NEW YORK: Albany (518/785-5876), Finger Lakes NY (315/451-4278), Hudson Valley (914/928-3575), Long Island (631/462-0490), New York City (212/481-0534), Binghamton (607/723-8824), Western NY State (716/810-1664), Northern New York (215/742-1060)
NORTH CAROLINA: Richmond, VA (804/672-2234)
NORTH DAKOTA: Fargo (701/293-1300)
OHIO: Vandalia [American Line Builders] (937/898-5824), Columbus (614/481-8558), Cincinnati (513/791-8777), Cleveland (216/398-8440), Akron (330/384-1242), Youngstown (330/726-5525), Toledo (419/666-6040), Dayton (937/299-0384)
OKLAHOMA: Tulsa (918/749-9449), Oklahoma City (405/848-8621)
OREGON: Eugene (541/686-8035) Portland (503/233-5787)
PENNSYLVANIA: Philadelphia (215/732-1444), Philadelphia [Northeastern Line Constructors] (610/489-1272), Pittsburgh (412/432-1155)
RHODE ISLAND: Providence (401/785-2990)
SOUTH CAROLINA: Richmond, VA (804/672-2234)
SOUTH DAKOTA: Fargo, ND (701/293-1300)
TENNESSEE: Chattanooga (423/894-4357), Memphis (901/366-9010), Nashville (615/383-7051)
TEXAS: El Paso (915/778-4295), Arlington (817/633-3332), Amarillo (806/373-0281), Wichita Falls (940/691-1164), San Antonio (210/226-6331), Houston (713/977-2522)
UTAH: Salt Lake City (801/486-6900), Sandy [Western Line Constructors] (801/943-2081)
VERMONT: Springfield, MA (413/785-1337)
VIRGINIA: Richmond (804/672-2234)
WASHINGTON: Everett (425/258-2644), Spokane (509/328-9670), Seattle (206/284-2150), Tacoma (253/584-4095)
WEST VIRGINIA: Charleston (304/346-1331)
WISCONSIN: Milwaukee (414/778-0305), Madison (608/221-4650)
WYOMING: Casper (307/234-8142)

INTERNATIONAL CHAPTERS:
AUSTRALIA: New South Wales (02-9744-1099), Queensland (7-3252-7488), Victoria (61-3-9645-5533), NECA National [Australia] Office (61-3-9645-5566), South Australia (61-8-8272-2966)
CANADA: Toronto, Ontario (416-391-3226)
MEXICO: Mexico, D.F. (525/611-5414) Guadalajara (523/671-0976), Monterrey (528/338-8323)
NEW ZEALAND: Ecanz (64-4-385-9657)

Index No. 302598
Marketing
8K/12/99

Downtime puts you out of the game. NECA contractors keep you on top of it.

DOWNTIME CAN BRING AN ENTIRE BUSINESS DISTRICT TO A STANDSTILL AND COST COMPANIES MILLIONS OF DOLLARS A MINUTE. THE RISK OF ENORMOUS LOSSES PUTS FACILITY MANAGERS AND OWNERS ON THE LINE — EVERY DAY.

Today's building systems and equipment are increasingly sensitive and interrelated, and more and more operations are run on a 7 x 24 schedule. That makes a commitment to reliability absolutely critical.

Rely on NECA electrical contractors and you can bring building systems and equipment to a higher level of performance — before a critical problem develops. With a NECA contractor on the job, you are assuring yourself and your tenants of electrical installations that are the very definition of quality. NECA contractors adhere to the National Electrical Installation Standards™, which call for a level of quality over and above the minimum safety requirements of the National Electrical Code.

Don't let downtime put you out of the game. Call 1-800-888-NECA or visit the Web site to find a NECA contractor best qualified for your particular project.

*Ask for your free copy of **Electrical System Reliability — Inside and Out**, a guide to evaluating the needs of your facility, predictive testing and maintaining reliability today and beyond.*

NECA

Make a powerful connection.

www.necaconnection.com