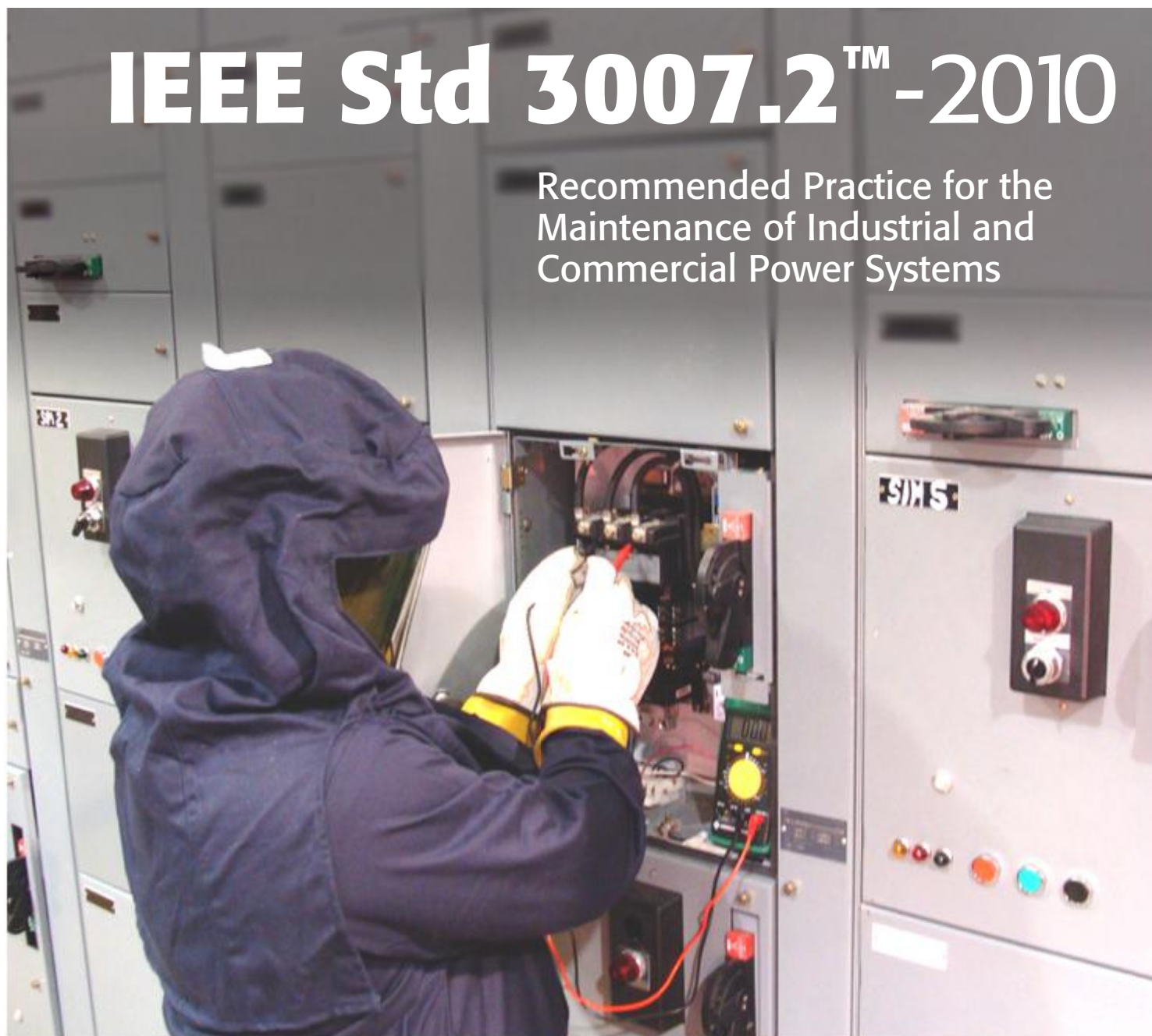


IEEE Std 3007.2™-2010

Recommended Practice for the
Maintenance of Industrial and
Commercial Power Systems



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IEEE Recommended Practice for the Maintenance of Industrial and Commercial Power Systems

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Abstract: This recommended practice covers the maintenance of industrial and commercial power systems. It covers the fundamentals of electrical equipment maintenance, how to develop successful maintenance strategies, and the common testing methods used as part of an electrical equipment maintenance program.

Keywords: failure effect; failure mode; failure modes and effects analysis; failure modes, effects, and criticality analysis; hidden/latent failure; maintenance; predictive maintenance; preventive maintenance; probability; reliability; reliability-centered maintenance; safety-related work practices

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Introduction

This introduction is not part of IEEE Std 3007.2-2010, IEEE Recommended Practice for the Maintenance of Industrial and Commercial Power Systems.

IEEE P3000 Series

This recommended practice was developed by the Technical Books Coordinating Committee of the Industrial and Commercial Power Systems Department of the Industry Applications Society as part of a project to repackage IEEE's popular series of "color books." The goal of this project is to speed up the revision process, eliminate duplicate material, and facilitate use of modern publishing and distribution technologies.

When this project is completed, the technical material in the thirteen color books will be included in a series of new standards—the most significant of which will be a new book, IEEE Std 3000™, Recommended Practice for the Engineering of Industrial and Commercial Power Systems. The new book will cover the fundamentals of planning, design, analysis, construction, installation, startup, operation, and maintenance of electrical systems in industrial and commercial facilities. Approximately 60 additional "dot" standards, organized into the following categories, will provide in-depth treatment of many of the topics introduced by IEEE Std 3000:

- Power Systems Design (3001 series)
- Power Systems Analysis (3002 series)
- Power Systems Grounding (3003 series)
- Protection and Coordination (3004 series)
- Emergency, Standby Power, and Energy Management Systems (3005 series)
- Power Systems Reliability (3006 series)
- Power Systems Maintenance, Operations, and Safety (3007 series)

In many cases, the material in a "dot" standard comes from a particular chapter of a particular color book. In other cases, material from several color books has been combined into a new "dot" standard. The material in this recommended practice largely comes from Chapter 5 and Chapter 6 of IEEE Std 902™-1998^a and Chapter 8 of IEEE Std 446™-1995 [B29].^b

IEEE Std 3007.2

The research and analysis of the optimum maintenance program for electrical equipment have been ongoing tasks of the maintenance manager for as long as electrical equipment has been used to support facility or plant operation. In spite of the findings from decades of analysis, maintenance programs still vary from breakdown maintenance programs to sophisticated preventive maintenance programs. Preventive maintenance programs may include predictive maintenance as well as a more sophisticated reliability-centered program. The many variables, from the types of electrical equipment to the types of applications in which they are used, make the universal definition of an exact maintenance program difficult. It is believed almost universally, however, that some form of maintenance is necessary.

^a Information on references can be found in Clause 2.

^b The numbers in brackets correspond to the numbers of the bibliography in Annex A.

NFPA 70B-2006 [B45] states the following:

“Electrical equipment deterioration is normal, but equipment failure is not inevitable. As soon as new equipment is installed, a process of normal deterioration begins. Unchecked, the deterioration process can cause malfunction or an electrical failure.”

It is necessary to control equipment deterioration in order to maintain the use for which the equipment and systems were originally designed and installed. Although most parties would agree that preventive maintenance is necessary for the reliability of electrical power systems, there remains a wide disparity about the content of a preventive maintenance program.

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1. Scope

This recommended practice covers the maintenance of industrial and commercial power systems. It covers the fundamentals of electrical equipment maintenance, how to develop successful maintenance strategies, and the common testing methods used as part of an electrical equipment maintenance program.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE P3007.3™/D1, April 2010, Recommended Practice for Electrical Safety of Industrial and Commercial Power Systems.^{1, 2, 3}

IEEE Std 902™-1998, IEEE Guide for Maintenance, Operations and Safety of Industrial and Commercial Power Systems (*The Yellow Book*).

¹ Numbers preceded by P are IEEE authorized standards projects that were not approved by the IEEE-SA Standards Board at the time this publication went to press. For information about obtaining drafts, contact the IEEE.

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3. Definitions, abbreviations, and acronyms

3.1 Definitions

For the purposes of this recommended practice, the following terms and definitions apply. *The IEEE Standards Dictionary: Glossary of Terms & Definitions* should be referenced for terms not defined in this clause.⁴

breakdown/corrective maintenance: Repair actions that are conducted after a failure in order to restore equipment or systems to an operational condition.

electrical equipment: A general term that is applied to materials, fittings, devices, fixtures, and apparatus that are a part of, or are used in connection with, an electrical installation. This term includes the electrical power generating system; substations; distribution systems including cable and wiring; utilization equipment; and associated control, protective, and monitoring devices.

failure effect: A description of how the failure affects the device involved in the failure as well as other equipment in the system.

failure mode: The way a piece of equipment fails, such as open or short circuited, or a description of what has failed to operate properly, such as loss of communication with a sensor.

failure modes and effects analysis (FMEA): The identification of significant failures, irrespective of cause, and their consequences. This term includes electrical and mechanical failures that could conceivably occur under specified conditions and their effect on system operation, adjoining circuitry, or mechanical interfaces.

failure modes, effects, and criticality analysis (FMECA): The identification of significant failures, their consequences, and their criticality. Analyzing failure criticality involves classifying or prioritizing the level of importance for each failure based on the failure rate and the severity of the effect of failure.

hidden/latent failures: An abnormal or detrimental condition about which no one would know in the normal course of operation. An example is a device failure that does not occur immediately at the time of overstress, but sufficiently weakens the device so that it later fails under normal operating conditions.

maintenance: The act of preserving or keeping in existence the conditions that are necessary in order for equipment to operate as it was originally intended.

predictive maintenance: The practice of conducting diagnostic tests and inspections during normal equipment operations in order to detect incipient weaknesses or impending failures.

preventive maintenance: The practice of conducting routine inspections, tests, and servicing so that impending troubles can be detected and then reduced or eliminated.

probability: A number expressing the likelihood of the occurrence of a given event, especially a fraction expressing how many times the event will happen in a given number of trials.

reliability: The probability that a product or service will operate properly for a specified period of time under design operating conditions without failure.

⁴ The IEEE Standards Dictionary: Glossary of Terms & Definitions is available at <http://shop.ieee.org/>.

reliability-centered maintenance (RCM): A systematic methodology that establishes initial preventive maintenance requirements or optimizes existing preventive maintenance requirements for equipment based upon the consequences of equipment failure. The failure consequences are determined by analyzing the possible failure modes of each component in an operating system and determining what effect that failure would have on the system and overall mission.

safety-related work practices: The procedures and actions defined in safety standards such as NFPA 70E-2009 [B46]⁵ to minimize the exposures and risks of working on or around electrical equipment.

3.2 Abbreviations and acronyms

ASD	adjustable speed drive
CT	current transformer
DF	dissipation factor
EMI	electromagnetic interference
EPM	electrical preventive maintenance
EPR	ethylene propylene rubber [cable]
FMEA	failure modes and effects analysis
FMECA	failure modes, effects, and criticality analysis
hi-pot	high-potential
ICCB	insulated-case circuit breaker
MCCB	molded-case circuit breaker
PD	partial discharge
PF	power factor
PILC	paper-insulated lead-covered [cable]
PT	potential transformer
RCM	reliability-centered maintenance
TTR	transformer turns ratio
UPS	uninterruptible power supply
VRLA	valve-regulated lead-acid [battery]
VT	voltage transformer
XLPE	cross-linked polyethylene [cable]

4. Preventive maintenance

The implementation of this recommended practice requires that the proper safety procedures be used as an integral part of the process. All of the recommendations provided here assume IEEE P3007.3⁶ or the safety chapters of the prior document, IEEE Std 902-1998, are also being followed in conjunction with this document.

⁵ The numbers in brackets correspond to the numbers of the bibliography in Annex A.

⁶ Information on references can be found in Clause 2.

4.1 Program basis

Most people recognize the need for the maintenance of electrical equipment. The debate really focuses on how much maintenance is enough. The key to the discussion about the proper amount of maintenance centers on the economic balance between the cost of performing maintenance and the importance of reliable power. For example, a computer center with a downtime cost of US\$100,000 or more an hour would justify a much more extensive maintenance program than would a small facility whose downtime cost is not as great.

Moreover, it has been shown that there is a balance to the amount of economic benefit that is achieved from performing maintenance. A lack of maintenance eventually results in failures and a high cost to a plant. Likewise, an excessive amount of maintenance may be wasteful and also may result in a high cost to a plant. It can also introduce additional opportunities for failure in several ways. The most obvious is that every time maintenance is performed is another opportunity for a mistake to be made by the individual(s) performing the maintenance. For some types of equipment, taking it apart itself introduces significant stress on the bolts, fasteners, etc. There are also cases in which only part of the system (usually a redundant part) is shut down while the rest of the system is in operation. Should a failure occur in the remaining system while the redundant part(s) are not available, the overall system experiences an outage. The optimum maintenance program lies somewhere in between. This balance point can vary for different types of facilities.

There are two benefits to having an effective electrical preventive maintenance (EPM) program. The first benefit is enhanced safety and system performance. The system operates as it was designed, and if a section of the distribution system does have a failure, the protection isolates the minimum amount of equipment. The second benefit is that both the costs of production loss and failure repair are reduced since the problems are located and corrected before a catastrophic failure occurs. Other intangible benefits include improved employee morale, better workmanship, increased productivity, reduced absenteeism, reduced interruption of production, and improved insurance considerations. In planning an EPM program, consideration should be given to the costs of safety, the costs associated with direct losses due to equipment damage, and the indirect costs associated with downtime or lost or inefficient production.

EPM is not only important for the reliability and integrity of electrical systems, it is also important for the safety and protection of people. With regard to personnel protection, Section 110.8(B)(1)(b) of NFPA 70E-2009 [B46] recommends that an arc-flash hazard analysis be performed and that an arc-flash protection boundary be established prior to commencing any work, and Section 130.3 of NFPA 70E-2009 provides the requirements for conducting such a study. All calculations for determining the incident energy of an arc and for establishing a flash protection boundary require the arc clearing time. This clearing time is derived from the engineering coordination study, which is based on what the protective devices are designed and adjusted to do. NFPA 70E-2009 also cautions that improper maintenance can adversely impact arc-flash hazards. An EPM program reduces hazards to employees as well as reducing the risk of failure or malfunction of electrical systems and equipment.

With the proper mixture of common sense, training, manufacturers' literature, and spare parts, proper maintenance can be performed to maximize the safety and reliability of power systems. Electrical equipment, if installed within its ratings and properly maintained, should operate trouble-free for many years. However, if operated outside of its ratings or without proper maintenance, catastrophic failure of the power system, circuit breaker, or switchgear can occur and cause not only the destruction of the equipment but also serious injury or even death of employees working in the area.

In order to protect electrical equipment and people, proper preventive maintenance should be performed on the equipment. In addition to the manufacturers' literature, several standards and guides assist users with electrical equipment maintenance. When the overcurrent protective devices are properly maintained and tested for proper calibration and operation, equipment damage and arc-flash hazards can be minimized.

Examples of existing standards and guides to help users understand electrical equipment maintenance are ANSI/NETA MTS-2007 [B3] and NFPA 70B-2006 [B45].

4.2 Design considerations

An optimum EPM program considers the overall design and operation of the facility. A key strategy for supporting preventive maintenance is to schedule maintenance activities during planned outages. For example, if the facility is required to deliver power only during periods of peak load, then arrange maintenance activities during off-peak hours. If maintenance outages require special planning and will have significant impact on plant productivity and operations, consider design features that will optimize the maintenance process and/or reduce the duration of the outage on critical plant loads. Typical design features include redundant switchgear, alternate power sources such as uninterruptible power supply (UPS) and diesel generator, or critical load protective devices like draw-out circuit breakers (rather than fixed-mount circuit breakers).

For the “24/7” (24 hours a day, 7 days a week) continuous power facilities, such as data centers, refineries, hospitals, and semiconductor manufacturing, the design of the facility is critical. For these types of facilities, the requirement is often that the electrical distribution system be “concurrently maintainable.” Concurrently maintainable means backup equipment and redundant power paths are available so maintenance can be performed on individual parts of the critical system without an outage to the critical loads. The maintenance is performed while the facility is in operation and the critical loads are in service.

Additional consideration should be given to the accessibility of the electrical equipment for maintenance. Electrical equipment location can be critical to the maintenance process. An example would be electrical equipment installed in a basement that has only stairway access through which testing equipment can be brought down to the electrical equipment. In addition, access to the back of switchboards or switchgear may be necessary in order to perform thorough maintenance and inspection, but may be difficult if such devices are mounted against the wall.

The environment in which the equipment is installed can play an important part in maintenance. Where equipment is mounted (indoors or outdoors) and whether it is properly enclosed and protected from dust, moisture, and chemical contamination are all factors that influence the frequency with which maintenance tasks should be performed.

The design phase is also the period in which the establishment of baseline data for the equipment should be considered. Baseline data can be established by including in the design specifications the acceptance or startup testing of the equipment when it is first installed. The manufacturer’s instructions for required testing prior to energization should always be followed. The InterNational Electrical Testing Association (NETA) provides detailed specifications for electrical power equipment in ANSI/NETA ATS-2009 [B1].

Design drawings are important to an effective maintenance program. As-built drawings such as single-line and logic diagrams should be current and controlled. An accurate single-line diagram is crucial for safety and effectiveness in the operation of the equipment. Such drawings help the operator to understand the consequences of operating a circuit that could result in an undesirable plant transient or unplanned mode of operation. In addition, equipment tags or identifiers in the field should be matched to drawing descriptions of equipment. This simple adherence to plant design standards and drawing control is significant to preempting the accidental energization and/or deenergization of equipment.

As part of the procurement of the electrical equipment, consideration should be given to the tools and instruments that are required to perform effective maintenance, such as hoists; manual-lift trucks that are used to remove and install circuit breakers; circuit breaker electrical operation test stations; and specialty maintenance devices such as spring blocking devices, manual charge handles, and contact erosion indicators. These tools and instruments will help to maximize safety and productivity. Finally, the installation, operation, and maintenance manuals should be obtained, maintained, and provided to the personnel performing the maintenance. Some facilities keep the instruction manuals in a spare cubicle of the switchgear itself.

4.3 Creating an electrical preventive maintenance (EPM) program

To be successful, an EPM program must have the backing of management. There should be the belief that operating profit is increased through the judicious spending of maintenance dollars. Financial issues should be considered when evaluating the need for continuous electrical power. These factors will help to dictate the level of importance that a facility places on an EPM program. The cost of downtime or lost production, the increased hazards to employees, and ways to minimize these costs and hazards through effective maintenance should also be considered.

In setting up any EPM program, it is essential to be thoroughly familiar with electrical safety, including how to properly perform lockout and tagout of the equipment to be maintained. IEEE P3007.3 provides detailed information on electrical safety, including lockout and tagout.

A complete survey of the plant should be performed. This survey should include a listing of all electrical equipment and systems. The equipment should be listed in a prioritized fashion in order to distinguish the systems or pieces of equipment that are most critical to the operation. The survey should also include a review of the status of drawings, manuals, maintenance logs, safety and operating procedures, and training and other appropriate records. It should be recognized that the survey itself can be a formidable task. It is likely that power outages may be required in order to complete the survey. The gathering of documentation is important. This task includes not only the drawings of the facilities, but also all the documentation that is normally provided by the manufacturer of the equipment. The manufacturer's manuals should include recommended maintenance procedures, wiring diagrams, bills of materials, assembly and operating instructions, and troubleshooting recommendations.

Next, the necessary procedures for maintaining each item on the list should be developed. The manufacturer's instructions along with NFPA 70B-2006 [B45] and ANSI/NETA MTS-2007 [B3] are valuable resources that provide much of this information. Procedures should also be developed that integrate the equipment into systems. People who are capable of performing the procedures should be selected, trained, and qualified. At some level of technical performance, it may be desirable to contract parts of the maintenance program and to qualify outside firms, particularly for functions that require special test equipment to perform.

Finally, a process should be developed to administer the program. This process may be manual or software-based. There are many commercially available systems with varying levels of sophistication.

Consideration should also be given to some of the less technical parts of the process. Maintenance planning should include the logistics of getting equipment in and out of the area to be maintained, general safety procedures, emergency procedures, and any record keeping needed before the maintenance activity. Also, planning should include follow-up maintenance, special lighting needs, availability of emergency power, and equipment-specific safety precautions. In addition, emphasis should be given to keeping electrical equipment accessible and not blocked by stored materials.

4.4 Reliability-centered maintenance (RCM)

4.4.1 Overview of RCM

RCM is a systematic and comprehensive approach to the maintenance of systems and equipment in which reliability is critical. RCM was initially developed by the airline industry, but has since been adopted by several other industries. The process involves performing a failure modes, effects, and criticality analysis (FMECA) and then determining for each component what is the appropriate and effective preventive maintenance activity. All possible failure modes and appropriate preventive maintenance are evaluated for each component; thus a program is established that is proven to result in improved facility equipment and systems reliability. Other benefits include improved safety, decreased repair costs, shorter outages, reduced overhaul frequency, and improved management of spare parts.

The following outlines the important philosophical topics surrounding RCM:

- a) RCM is organized and documented common sense.
- b) The focus of RCM is to analyze and make changes to current EPM program activities in order to improve their applicability and cost-effectiveness.
- c) RCM evaluations determine the maintenance requirements of equipment based upon the function of the system and the way in which the equipment supports the function. An RCM-based maintenance program provides a technical basis for preventive maintenance activity that is not strictly based upon regulatory requirements, vendor recommendations, or industry standards.
- d) RCM focuses preventive maintenance resources on equipment that is critical to maintaining important system functions. RCM emphasizes proactive, predictive maintenance techniques over traditional, time-directed maintenance techniques.

Typical implementation of an RCM program involves taking an existing EPM program and modifying it to align with the “critical path” or “mission” of the facility. In a data center, such alignment would include everything necessary to keep the computers running, which includes the UPS as well as the air conditioning system. All the systems in the critical path would receive priority, while the remaining, nonessential support systems would receive much less attention.

4.4.2 RCM procedure

RCM is a different philosophical approach to maintenance. Instead of focusing on preserving the individual pieces of equipment, with RCM the approach is to preserve specific functions the equipment performs. The importance of the functions to the overall mission of the facility determines where the maintenance efforts will be focused. Therefore, in order to do RCM effectively, the operating context for the systems to be evaluated must be well defined and understood. In the design phase, the operating context is often called *the basis of design*, the document that defines the expected performance of the facility, system, or processes to be built.

For example, if RCM were to be performed for the electrical distribution system in a high-rise building, the operating context of the emergency switchboard that supplies life safety equipment is different from the switchboard that supplies power to tenant space on the fifth floor. The two switchboards could be identical, but because the life safety switchboard has a greater importance to the entire building, it may warrant more maintenance than the switchboard for a single area of the building. Therefore, the analysis of each part of the RCM has to be based on the operating context of the systems or processes being evaluated.

- a) Select the system(s) to be studied. Define the boundaries: What systems are included in this project? What systems are outside the scope of this project?