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AGING MANAGEMENT GUIDELINE FOR COMMERCIAL NUCLEAR POWER PLANTS - MOTOR CONTROL CENTERS

FINAL REPORT

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Abstract

This Aging Management Guideline (AMG) provides recommended methods for effective detection and mitigation of age-related degradation mechanisms in Boiling Water Reactor (BWR) and Pressurized Water Reactor (PWR) commercial nuclear power plant motor control centers important to license renewal. The intent of this AMG is to assist plant maintenance and operations personnel in maximizing the safe, useful life of these components. It also supports the documentation of effective aging management programs required under the License Renewal Rule 10 CFR Part 54. This AMG is presented in a manner that allows personnel responsible for performance analysis and maintenance to compare their plant-specific aging mechanisms (expected or already experienced) and aging management program activities to the more generic results and recommendations presented herein.

ACKNOWLEDGEMENTS

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Contents

Contents (continued)

Contents (continued)

Figures

Tables

AGING MANAGEMENT GUIDELINE FOR MOTOR CONTROL CENTERS

1. EXECUTIVE SUMMARY

1.1 Purpose and Objective

Continued operation of nuclear power plants for periods that extend beyond the original 40-year license period may be a desirable option for many U.S. nuclear plant operators. To allow operation of the plant to continue beyond the original licensing period, utilities must show that the components important to license renewal either do not age or will not age to the extent that they are incapable of supporting required functions. Therefore, to allow operation during a license renewal period, operators of nuclear power plants must manage the aging of components such that proper function is ensured.

The purpose of this aging management guideline (AMG) is to provide guidance for the effective management of aging of motor control centers (MCCs) used in safety-related and non-safety-related applications in nuclear power plants. An effective aging management program will ensure that MCCs will continue to perform their functions during the current and license renewal term.

The objective of this AMG is to provide an analysis of the potential age-related degradation mechanisms for MCCs and to provide acceptable guidelines for developing aging management programs for controlling significant degradation mechanisms. Use of these guidelines will provide utilities with a basis for verifying that an effective program for managing age-related degradation of MCCs is in place.

1.2 Scope

Motor control centers consist of switching and interrupting devices used to control and protect various types of electrical apparatus and circuits. The equipment covered by this guideline includes molded-case circuit breakers (MCCBs), motor starters and contactors, relays, wiring, terminal blocks, fuses, and the supporting MCC housing and buswork. Metal-clad switchgear is not within the scope of this guideline, but is covered by the Aging Management Guideline for Electrical Switchgear.

Motor control center components important to license renewal are addressed by this report. The group of equipment that is important to license renewal includes more equipment than just safety-related MCCs. For example, the definition of important to license renewal includes any component or system subject to a limiting condition for operability requirement in the plant's Technical Specifications. The definition of important to license renewal is contained in Section 2.5. The evaluation of the effect of this definition on the scope of a utility's aging management program for MCCs is discussed in Section 3.1. Although the types of MCCs contained in the grouping "important to license renewal" that are not safety related are essentially the same as safety-related MCCs, they may not have been maintained in the same mar as the safety-related MCCs. Therefore, utilities may choose to extend their maintenance practices used on safety-related MCCs to the additional MCCs covered by the scope of important to license renewal, or to otherwise demonstrate that these practices are not required to effectively manage the aging of the additional equipment.

The general classifications of MCCs that are contained within the grouping of MCCs important to license renewal are:

- 600-Vac*
- 250- and 125-Vdc.*

These MCCs typically supply single-phase, three-phase, and direct current motors ranging from fractional horsepower (hp) ratings up through non-reversing motors rated at 200 hp. The power and control cables connected to MCCs are not included within the scope of this document. The MCC housings, buswork, disconnects, circuit breakers, relays, contactors, fuse holders, wiring, and terminal blocks are within the scope of this document.

1.3 Conclusions of This Study

This study evaluated the stresses acting on MCC components, industry data on aging and failure of MCC components, and the maintenance activities performed on MCCs. The study evaluated the main subsystems within the MCCs, including MCCBs, magnetic contactors and starters, relays, control transformers, terminal blocks, wires, and fuse holders. The potential aging mechanisms resulting from environmental and operating stresses on MCCs were identified, evaluated, and correlated with actual plant experience to determine if the potential aging mechanisms were actually being experienced. Then, the maintenance procedures used by plant operators were evaluated to determine if the potential and actually experienced aging mechanisms were being identified and managed. Where an aging mechanism was properly managed, the procedures were deemed to be "effective." Where an aging mechanism was not fully managed or not considered, additional plant-specific activities to manage the aging mechanism were identified.

1.3.1 Potentially Significant Component/Aging Mechanism Combinations Managed by Effective Programs

Evaluation of the components of the MCCs, the stressors acting upon the components, and the operational history data indicates that nearly all MCC components have significant aging mechanisms that can affect their function. Evaluation of the failure history coupled with review of existing utility maintenance procedures shows that these aging mechanisms can be managed in the current and license renewal periods. The following list provides a summary of the components and the aging mechanisms, coupled with the maintenance and surveillance technique that manages the aging mechanism. Note: Many of the maintenance activities listed below (i.e.,

* The 600-Vac, 250-Vdc, and 125-Vdc designations will be used throughout the remainder of this document even thought some plants use systems with slightly different nominal voltages, such as 480 or 575 Vac.

visual inspections, cleaning, etc.) may be conducted concurrently, thereby allowing relatively rapid completion. Details of the inspection frequency are provided in Chapter 5. Appendix A provides definitions of the terminology used throughout the report.

MCC Components	Aging Mechanism(s)	Activities That Mitigate Effects of Aging Mechanisms
MCC Structural Components (including buswork, insulation, and housing)	Loss of insulator mechanical and insulating properties	Visual inspection for insulation tracking paths, signs of overheating, surface contamination, surface irregularities, cracking, embrittlement, and discoloration; cleaning; insulation resistance testing
	High resistance electrical connections,* loss of bolt integrity	Visual inspection of MCC buswork, ground bus, and chassis ground for loose or overheated electrical connections; warping; verification of tightness of connections and buswork bolts; infrared thermography
	Loosening/loss of fastener components	Verification of proper torque on the housing bolts and hardware; replacement as required
Molded-Case Circuit Breakers** (MCCB)	Deterioration of contact surfaces	Periodic operation for removal of contaminants and oxidation from contact surfaces; individual pole resistance test, operational testing
	Material fatigue and embrittlement	Visual inspection of MCCB casing for cracks, chipping, or signs of overheating
	Wear or binding of internal MCCB components	Operational testing, freedom of movement of operating mechanism
	Wear of external operating handle	Visual inspection for wear, inadequate lubrication, loss of tolerances; lubrication, cleaning, or adjustment; operability testing
	Deterioration of bus/cable connections	Visual inspection and mechanical verification of MCCB bus and load terminations
	Variation of setpoint of bimetallic trip element	Operational trip test
	Deterioration of lubricants	Verification of the freedom of motion of the operating handle/mechanism during cycling

*The aging mechanism of high resistance electrical connections is applicable to all power path components within the MCC enclosure; hence, it will only be described for this component.

**Includes the MCCB as well as the external operating handle and linkage.

MCC Components	Aging Mechanism(s)	Activities That Mitigate Effects of Aging Mechanisms
Molded-Case Circuit Breakers (continued)	Current-limiting fuse* failure	Functional trip test
	Surface current tracking/loss of insulating properties	Visual inspection of insulation for tracking paths, signs of overheating, surface contamination, surface irregularities, cracking, embrittlement, and discoloration; cleaning of internal components and insulating surfaces; insulation resistance testing**
Magnetic Contactor/ Starter	Insulation deterioration	Visual inspection of coils for damage, deterioration, and signs of overheating or localized burning; verification of freedom of armature movement (identifies melting of coil materials)
	Prolonged energization	Visual inspection of coil and other components for signs of overheating, flowing, or burning of materials
	Cyclic fatigue of armature/ contact assembly	Visual inspection of the coils for cracks, damage, and verification of the freedom of motion of the armature
	Wear/binding of contactor, auxiliary contacts, or interlock mechanisms	Visual inspection for dirt, contaminated lubricant, wear or loss of tolerances of components; operational testing; cleaning, adjustment, lubrication, and replacement as required
	Contact surface degradation	Cleaning/burnishing of contacts; visual inspection for cracking, burning, pitting, wear, and corrosion; refinishing or replacement if necessary
Thermal Overload Relay	Degradation of heater or bimetallic element	Visual inspection of elements for overheating or other damage; operational testing; replacement
	Binding of mechanical components	Verification of component freedom of movement; inspection; lubrication, adjustment, or replacement
	Contact surface degradation	Visual inspection; cleaning or burnishing
	Thermal degradation of organic materials	Visual inspection of heater support and other relay components for overheating, embrittlement, cracking, or other damage; cleaning or replacement as required

*Only applicable to MCCBs with current-limiting fuses installed.

**These activities are possible only for MCCBs with accessible internal components.

MCC Components	Aging Mechanism(s)	Activities That Mitigate Effects of Aging Mechanisms
Miscellaneous Relays	Prolonged energization; organic material breakdown	Visual inspection of coil and other relay components for overheating, burning, or flowing of materials
	Contact surface degradation	Visual inspection for corrosion, wear, or oxidation of contact surfaces; resistance testing; cleaning/replacement as required
	Wear and binding of contact mechanism/armature	Visual inspection; freedom of movement, operational tests
Control Transformers	Insulation degradation	Inspection of overheating, cracking, or burning of insulation; infrared thermography; replacement
	Conductor failure	Continuity/resistance measurement; replacement
Terminal Blocks	Degradation of organic materials	Visual inspection of terminal block for signs of overheating, embrittlement, cracking, or other damage; cleaning or replacement as required
	Degradation of hardware	Visual inspection for terminals, nuts, screws, sliding links, fuse holders (if equipped), and mountings for damage, deterioration, or loss; tightening, repair, or replacement as required
	Loss of insulating properties	Visual inspection of block for tracking paths, overheating, surface contamination, surface irregularities, cracking, embrittlement, and discoloration; cleaning or replacement as required
Control Wiring	Failure of insulation and/or conductor	Visual inspection of insulation for cutting, chafing, cracking, overheating; inspection for bending, twisting, breaking of conductor; cleaning and replacement as required
Fuse Holders	Fatigue of fuse clip	Visual inspection for fatigue or wear of fuse clip and adequate pressure on ferrules; replacement as required
	High resistance/worn contact surfaces	Visual inspection for signs of oxidation, corrosion, contaminants, or overheating; cleaning/burnishing; replacement

Table 5-1 provides additional detail for the MCC components listed above. All of the significant aging mechanisms were amenable to aging management through currently available maintenance and surveillance techniques.

1.3.2 Non-significant Component/Aging Mechanism Combinations

The review of MCC component aging mechanisms identified a potential for structural deterioration of the metal housing of the MCC caused by material degradation, fatigue, or loss of fastening of components. A review of the operational history of the MCC identified no cases in which MCC housing failure has occurred to date. (Note: Failures of other associated subcomponents, such as interlock switches, have occurred; however, no actual failures of the metal housing or other structural components have been documented). In typical nuclear plant applications, this equipment is located in relatively cool, low-moisture and contaminant-free environments such that the presence of corrosion or other degradation mechanisms is minimized. Any instances of significant housing degradation would also likely be detected during routine plant maintenance and surveillance efforts and addressed so that their continued effects would be mitigated. Based on these observations and assumptions, the conclusion that MCC housings will not experience significant degradation during the license renewal period is warranted. Therefore, unless the MCC is located in high moisture/corrosive environments, structural deterioration of the metal housing is not a significant aging mechanism. In those cases where the equipment is located in such a corrosive environment, aging of the housing and structural components during both the current and license renewal terms may be significant, and must be addressed by appropriate inspection and maintenance practices. Aging mechanisms associated with MCC housings are further discussed in Section 4.2.

1.3.3 Potentially Significant Component/Aging Mechanism Combinations Requiring Plant-Specific Management

Section 5 of this report evaluates the maintenance procedures for MCCs and concludes that MCCs maintained in accordance with the guidance in Section 5.2 and Table 5-1 will be subject to an effective maintenance program as required for license renewal, subject to the following possible limitations:

- Molded Case Circuit Breakers. Molded case circuit breakers constituted the highest fraction of failures noted in MCC components. Diagnostic techniques (such as overcurrent trip and pole resistance testing) that are employed at many plants to evaluate molded case breaker performance appear effective at identifying failed breakers and subcomponents, yet the ability to identify degradation in the breaker prior to the point of failure is limited. This is evidenced by the fact that roughly two of every five MCCB-related failures were detected during plant operations.

- Breaker Operating Handles/Linkages. Motor control centers from several manufacturers appeared to have problems associated with the external breaker operating handle and linkage; current maintenance procedures do not appear to completely address these types of failures. In certain plants, these components may affect the safety function of the associated load during accident conditions.

- Starter/Contactor Mechanical Assemblies. Industry failure data indicate that current maintenance procedures may not be fully effective at mitigating main contactor, interlock, and auxiliary contact mechanism failures.

Accordingly, nuclear plant operators experiencing substantial rates of in-service MCCB, external operating handle, and starter/contactor mechanism failure should consider implementing the following actions:

1. Review and evaluate the adequacy of existing maintenance and testing programs with relation to the manufacturer's recommendations and other industry guidance.

2. If existing testing and maintenance procedures appear to be adequate, then conduct further analysis of component failures to identify problematic equipment types or failure modes. If existing testing and maintenance procedures are not adequate, upgrade the procedures as necessary.

3. If significant failure trends are noted for MCC components, conduct a root-cause evaluation. Implement those corrective actions necessary to mitigate the effects of the identified causes.

In addition, plant-specific review of the maintenance program is required if:

- The MCC and its internal components are exposed to temperatures in excess of 104°F for extended periods. Then: The periodicity of maintenance and surveillance must be reviewed to verify that organic materials (such as lubricants, greases, or epoxies) used in various subcomponent applications have not been adversely affected by the operating temperature.

- The MCC is required to be qualified for accident environments. Then: The maintenance requirements for aging management must be consistent with maintenance requirements driven by equipment qualification rules (such as periodic replacement of components at set intervals).

- Individual MCC subcomponents are subject to high cycle* operation (e.g., loads controlled by these components are repetitively cycled or actuated on a very frequent basis, such as temperature-controlled fans or level control pumps). Then: The periodicity of maintenance for these components should be reviewed to determine if maintenance should be performed at a frequency consistent with the elevated number of cycles.

More information on these issues is contained in Section 6.

Review of the operation history of plant MCCs as portrayed by Nuclear Plant Reliability Data System (NPRDS) and Licensee Event Report (LER) data, as well as other industry studies, indicates that additional attention may be warranted for some subcomponents of certain manufacturers' equipment. The data indicate that certain subcomponents degrade or fail at a

* The definition of high cycle will vary based on the individual component; for example, contactor assemblies may be designed for a hundred thousand or more cycles, whereas molded case breakers may be designed for only several thousand cycles. Applicable standards and manufacturer's guidance should be consulted to determine the endurance rating for a given MCC component.

higher frequency than other subcomponents in the same type of MCC. These specific concerns are detailed in Section 6.1.3. Plant-specific review of the operating history of these MCC types and their applications will determine if these subcomponents require heightened attention. In addition, existing plant maintenance procedures should be reviewed to verify that sufficient depth of detail exists with regard to the inspection and evaluation of these potentially more problematic components.

Additional considerations for MCC Maintenance include the use of component "as-found" condition information, analysis and characterization of the equipment's normal operating environment, and the insights of plant maintenance organization personnel. Complete and accurate documentation of this information (as well as component failures data) is an important part of an effective maintenance program; detailed history and knowledge of component failure rates, modes, and causes permits a more precise application of corrective and preventive measures.

1.4 References

None.

2. INTRODUCTION

2.1 Background

The DOE-sponsored Plant Lifetime Improvement (PLIM) Program, in cooperation with the Electric Power Research Institute (EPRI) Life Cycle Management (LCM) Program, is establishing and demonstrating a predictable license renewal process for existing light water reactors (LWRs) in the United States An important element of this program was the development of Nuclear Management and Resources Council (NUMARC) License Renewal Industry Reports (IRs), which cover critical classes of equipment such as reactor pressure vessels, reactor coolant pressure boundary piping, containment structures, and electrical equipment. To support continued demonstration of PLIM and LCM concepts, there is a need for further industry development of guidelines that describe and evaluate acceptable aging management approaches for several groupings of equipment not evaluated in the IRs. This Aging Management Guideline (AMG) evaluates motor control centers (MCCs) determined to be important to license renewal.[2.1]

Continued operation of nuclear power plants for periods that extend beyond the original 40-year license period may be desirable for many U.S. nuclear plant operators. To allow operation of the plant during a license renewal period, utilities must show that the aging of components important to license renewal that are subject to age-related degradation unique to license renewal has been managed such that these components will not degrade to the extent that they are incapable of supporting required functions. Therefore, to control the aging of components important to license renewal during the license renewal period, operators of nuclear power plants must identify and perform activities necessary to manage the aging of components so that proper function is ensured.

For components to retain function during the license renewal period, activities such as preventive maintenance and refurbishment may be necessary during the current license period even though some of these activities may not have been necessary to guarantee function during the current license period. These activities would be necessary to ensure that there is no loss of required functions, no unacceptable reduction in safety margins, and that higher rates of challenge to plant safety systems do not occur during the license renewal period.

2.2 Purpose and Objectives

The purpose of this AMG is to provide cost-effective, practical methods to plant technical staff for the effective management of aging of motor control centers used in commercial nuclear power plants. An effective aging management program will ensure that each MCC component will continue to perform its function or will not prevent performance of a required function during the license renewal term.

The objective of this AMG is to provide an analysis of the potential degradation modes for motor control centers and to provide acceptable guidelines for developing effective aging management programs that control significant age-related degradation mechanisms.

This AMG is intended for use by nuclear plant personnel performing motor control center aging evaluations and to provide additional information and guidance in the formulation of their aging management programs. This AMG also provides additional value to nuclear plant operators as follows:

1. The AMG is a well-researched technical document that can be used by maintenance and system engineering personnel for the identification, characterization, and management of age-related degradation in MCCs. It can also be applied to a variety of the proposed approaches for the Integrated Plant Assessment (IPA). For example, the AMG can be used to resolve aging issues and devise effective programs for the management of aging occurring during both the current and license renewal periods. Failure data presented in the guideline may also be used to help justify that current maintenance practices are effective at mitigating equipment functional failures.

2. The results in this AMG are based on an extensive literature search. Therefore, nuclear plant personnel can use this AMG as a primary source document for relevant information about motor control centers. Some of the references used include:

   - EPRI Reports
   - EPRI Nuclear Maintenance Applications Center (NMAC) Reports and Maintenance Guides
   - U.S. Nuclear Regulatory Commission (NRC) Bulletins, Information Notices, Circulars, Generic Letters, and Reports
   - Code of Federal Regulations (CFR)
   - Vendor Manuals
   - American National Standards Institute (ANSI) and Institute of Electrical and Electronics Engineers (IEEE) Standards
   - Foreign References and Technical Papers

3. This AMG consolidates historical maintenance and industry operating information into one source. The plant maintenance/system engineer will find this useful for both the identification of age-related degradation (including root causes) and the verification of appropriate corrective action. Issues discussed in the AMG include:

   - Equipment design differences relevant to aging considerations
   - Equipment obsolescence as it affects aging management
   - Service environments

- Operating and maintenance history from the Institute for Nuclear Plant Operation (INPO) NPRDS and NRC LER databases

- Additional operating and maintenance history from responses to plant surveys

4. MCC aging phenomena are described in detail. This will be useful for MCC maintenance interval and reliability evaluations. The following topics are discussed:

   - Stressors acting on MCCs and their components
   - Aging mechanism identification
   - Significance of aging mechanisms using "if-then" criteria
   - Age-related degradation of MCCs
   - Potential failure modes

5. The AMG can be an effective tool for MCC aging management and personnel training. That is, it:

   - Identifies the need for aging management and compliance with maintenance rule requirements;
   - Contains a correlation between the scope and frequency of maintenance practices and MCC performance and rate of degradation;
   - Presents information that can be used in the construction of meaningful life-cycle management charts and to improve the accuracy of cost/benefit determinations;
   - Discusses both conventional and non-conventional maintenance techniques, and considers how these practices can be utilized to effectively manage equipment aging;
   - Characterizes initiation and progression of equipment aging for use in training personnel responsible for maintenance and inspection activities; and
   - Identifies concepts, principles, and methods for evaluating MCCs not in the scope of this guideline.

2.3 Contents of Aging Management Guideline

Motor control centers are systems of related electrical components used to control and protect various types of electrical apparatus and power circuits. MCCs are used in various applications throughout a nuclear plant. Plant ventilation, containment isolation, and emergency service water are just a few of the systems that are served by MCCs. The equipment covered by this guideline includes circuit breakers (the molded-case variety); motor starters and contactors; control, protective, and timing relays; control wiring; control transformers; terminal blocks; fuses and fuse holders; and the supporting MCC housing and buswork. Motor control centers and components from the following manufacturers are addressed in this report:

- Cutler-Hammer
- General Electric
- ITE/Gould
- Klockner-Moeller
- Westinghouse

In addition, failure data (where available) were reviewed for a variety of other MCC component manufacturers, including:

- Agastat/Amerace
- Allen-Bradley
- Arrow
- Furnas
- GTE-Sylvania
- Heinemann
- MSD/Struthers-Dunn
- Power Conversion
- Siemens-Allis*
- Sola
- Square-D
- Zurn

The general classifications of MCCs that are contained within the classification of MCCs important to license renewal are:

- 600-Vac
- 250- and 125-Vdc**

* Siemens, Siemens-Allis, and ITE may be synonymous for certain equipment.

**The 600-Vac, 250-Vdc, and 125-Vdc designations will be used through the remainder of this document even though some plants use systems with slightly different nominal voltages, such as 480 and 575 Vac.

Power distribution and control cables (up to the point of termination within the MCC) are not within the scope of this document.

Section 3 lists and describes the components evaluated, component boundaries and discusses manufacturers' design differences. It also includes a discussion of the design requirements that apply to MCCs, including applicable Codes, Standards, and Regulations. Lastly, Section 3 includes a detailed study of the operating history of the components evaluated from LER data, NPRDS data, and from other sources.

Section 4 discusses stressors acting on the subcomponents. Stressors acting over time produce aging mechanisms that ultimately can cause component degradation. The results of aging studies are used to describe aging mechanisms known to cause degradation. An aging mechanism is significant when, if allowed to continue without detection or mitigation measures, it will cause the component to lose its ability to perform its required function. Aging mechanisms for the subcomponents are identified and evaluated. Operational demands, environmental conditions, failure data, and industry operations and maintenance history are considered, and the significance of the aging mechanisms determined.

Section 5 discusses effective aging management techniques for aging mechanisms determined to be significant in Section 4. Common maintenance, inspection, testing, and surveillance techniques or programs are described. A brief discussion of less common activities and techniques is also included. The effectiveness of these techniques or programs to manage the significant aging mechanisms is studied. Variations in plant aging management programs or techniques are considered. Requirements for an effective technique or program are presented in the form of "if-then" criteria whenever possible.

Section 6 discusses management options to deal with action items identified in Section 5. Refurbishment criteria are also discussed.

2.4 Generic License Renewal Requirements

10 CFR 54.21[2.2] describes the requirements for the content of technical information in the license renewal application. Section 54.21 states that a supplement to the Final Safety Analysis Report (FSAR) must be prepared that contains an IPA that must:

1. identify and list all systems, structures, and components (SSCs) important to license renewal.

2. identify those structures and components (SCs) that contribute to the performance of a required function or could, if they fail, prevent an SSC important to license renewal from performing its required function.

3. for the identified SCs, determine those that could have age-related degradation that is unique to license renewal.

To identify the age-related degradation* that is unique to license renewal (in item (a)(3) of Section 54.21), the definition of age-related degradation unique to license renewal must be applied. Age-related degradation unique to the license renewal period is degradation:

1. that occurs during the term of the current operating license, but whose effects are different in character or magnitude after the term of the current operating license (the period of extended operation); or

2. whose effects were not explicitly identified and evaluated by the licensee for the period of extended operation and the evaluation found acceptable by the NRC; or

3. that occurs only during the period of extended operation.

The criteria for determining SSCs important to license renewal, the criteria for evaluating whether an SC is necessary for the performance of a required function, and the technical criteria used to determine whether an SC is subject to age-related degradation unique to license renewal must be defined.

For each of the SCs having age-related degradation that is unique to license renewal, the age-related degradation must be addressed by an effective program or shown not to need to be addressed by an effective program. An effective program is a documented program to manage age-related degradation unique to the license renewal period that ensures that an SSC important to license renewal will continue to perform its required function or will not prevent the performance of a required function during the period of extended operation.

The effective program must:

1. identify and mitigate age-related degradation unique to license renewal

2. contain acceptance criteria against which the need for corrective action can be evaluated and ensure timely corrective action when the acceptance criteria are not met

3. be implemented by the facility operating procedures and reviewed by the onsite review committee.

10 CFR 54.21 continues with a discussion of changes to the current licensing basis and plant modifications, which are outside the scope of this report.

Additionally, this AMG supports the determination that existing aging management practices are satisfactory for fulfilling license renewal requirements and meeting review conditions stated in the draft version of NUREG-1299, "Standard Review Plan for the Review of License Renewal Applications for Nuclear Power Plants."[2.3] Components included in the classification of "important to license renewal" are identified, and stressors, aging mechanisms, and failure modes for these components are defined. Furthermore, this AMG states

* See list of definitions for aging terminology used in this report.

the type of existing practices that are acceptable for the management of aging as well as areas requiring further plant-specific evaluation. Exemptions and requests for relief (pursuant to 10 CFR 50.12 and 10 CFR 50.55a, respectively) were not considered under this AMG because these areas are plant-specific in nature and therefore must be considered on a plant-by-plant basis.

This report will evaluate motor control centers with respect to the requirements of 10 CFR 54.21 and will provide a discussion of the types of MCCs important to license renewal and the age-related degradation affecting components and subcomponents of this equipment. The following sections detail the analysis leading to the determination of age-related degradation and the means necessary to address it.

2.5 Method Used to Define Components Important to License Renewal

To determine the MCCs covered by license renewal requirements, the definition of SSCs important to license renewal[2.1] must be evaluated. The current definition of SSCs important to license renewal includes:

1. Safety-related SSCs, which are those relied upon to remain functional during and following design basis events to ensure:

    (i) The integrity of the reactor coolant pressure boundary;

    (ii) The capability to shut down the reactor and maintain it in a safe shutdown condition; or

    (iii) The capability to prevent the consequences of accidents that could result in potential offsite exposure comparable to the 10 CFR Part 100 guidelines.

2. All non-safety-related SSCs whose failure could directly prevent satisfactory accomplishment of any of the required functions identified in paragraphs (1) (i), (ii), or (iii) of this definition.

3. All SSCs relied on in safety analyses or plant evaluations to demonstrate compliance with the Commission's regulations for fire protection (10 CFR 50.48), environmental qualification (10 CFR 50.49), pressurized thermal shock (10 CFR 50.61), anticipated transients without scram (10 CFR 50.62), and station blackout (10 CFR 50.63).

4. All SSCs subject to operability requirements contained in the facility's Technical Specifications' Limiting Conditions for Operation.

The evaluation of this definition with respect to MCCs and the components determined to be important to license renewal is given in Section 3.1.

2.6 Method Used to Define Aging Mechanisms Assessed in This Study

To define the aging mechanisms assessed in this study, a two-part evaluation was performed. First, the effects of stressors, such as temperature, humidity, voltage, operating cycles, and radiation, on equipment operation were determined. The aging mechanisms associated with those stresses that cause degradation were then determined. This evaluation is contained in Section 4.1.

Second, industry-wide operating experience (particularly that reported in U.S. NRC LERs; Information Notices, Bulletins, and Circulars; and the NPRDS data) was examined. A review of the NRC Information Notices, Bulletins, and Circulars was conducted to identify age-related failures. The aging mechanisms associated with reported age-related failures were then determined. Events described in the NPRDS data and LERs were then analyzed for age-related deterioration and failures to identify the numbers of particular types of failures. The aging mechanisms associated with these failures were then determined. This review of industry-wide operating experience is contained in Section 3.6 of this guideline.

This multi-source analysis (i.e., using data from NPRDS and NRC documentation in conjunction with other industry studies) provides a descriptive characterization of equipment aging by using actual plant and vendor data to substantiate and refine those aging mechanisms postulated to occur because of stressors.

After a list of all possible aging mechanisms was developed, the significance of each aging mechanism was determined. Those aging mechanisms that were confirmed by operating or overhaul experience, had a high probability of occurrence, or would result in a loss of functionality having a large impact on equipment operation were designated as significant aging mechanisms Those aging mechanisms designated as significant are discussed in Section 4.2.1. The remaining aging mechanisms were then reviewed to determine if:

1. They were fully controlled by current preventive maintenance programs, and

2. Sufficient time had passed for the effects of the aging mechanism to be identified.

Items not prevented by current preventive maintenance programs but that had not had time for the effects to become detectable (by standard detection means) were deemed to be significant. Those remaining aging mechanisms that had sufficient time to be recognizable but had not occurred were designated non-significant and are discussed in Section 4.2.2. The aging mechanisms that are not addressed by current maintenance programs are discussed in Section 5.4.2. Effective management options for these aging mechanisms are identified in Section 6.1.

It should be noted that aging mechanisms and their associated degradations were not categorized either as occurring in the current license period or as being unique to license renewal. Aging as a whole is covered in this document. There is no generically applicable methodology that has been agreed upon for identifying those age-related degradation mechanisms that are unique to license renewal. Therefore, the approach herein identifies those techniques that manage aging mechanisms to preclude adverse effects during the current and license renewal periods. Because the age-related degradation unique to license renewal screen was not used, the scope of components important to license renewal in this AMG may be significantly larger than if the screen were used.

To provide a basis for the discussions of stressors, aging mechanisms, and failure modes, Section 3 describes MCCs that are in common use in the nuclear industry. Appendix A provides definitions of aging terminology used in this report.

2.7 References

2.1 10 CFR 54.3, "Requirements for Renewal of Operating Licenses for Nuclear Power Plants — Definitions," Federal Register, Vol. 56, No. 240, December 13, 1991, pp. 64976-64977.

2.2 10 CFR 54.21, "Requirements for Renewal of Operating Licenses for Nuclear Power Plants — Contents of Application — Technical Information," Federal Register, Vol. 56, No. 240, December 13, 1991, p. 64978.

2.3 NUREG-1299, "Standard Review Plan for the Review of License Renewal Applications for Nuclear Power Plants," U.S. Nuclear Regulatory Commission; Draft Report for Comment, November 1990.

3. EQUIPMENT/COMPONENTS EVALUATED

3.1 Results of Methodology Used to Select Components Important to License Renewal

For each plant entering license renewal, an assessment must be performed to identify MCCs that are important to license renewal. Per Paragraph 1 of the definition of license renewal provided in Section 2.5, all MCCs deemed safety related are important to license renewal. Paragraph 2 of the definition generally would not bring additional motor control centers into the scope of important to license renewal, whereas Paragraph 3 may by virtue of station blackout equipment requirements. More MCCs may be added to the list based on any Limiting Conditions for Operation (LCOs) existing in the Technical Specifications (see Paragraph 4 of the definition).[3.1] Reference 3.1 is representative of similar references.[3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9]

3.2 Listing of Components Evaluated

Each MCC component determined to be important to license renewal in Section 3.1 must be evaluated to determine if it could degrade during the license renewal period.

The following components are common to MCCs (although not all MCCs contain all of these components):

Motor control center structural components
  (including metal housing, bus structure, terminals, and disconnects)
Circuit breakers (molded case)
Magnetic contactors/starters
Control, timing, and general purpose relays
Control transformers
Thermal overload devices
Terminal blocks
Control wiring
Fuses/fuse holders
Switches

All of these components are described further in Section 3.4. Only control wiring contained within the MCC housing is included in the evaluation of MCC components. The control and power cabling connecting the MCC to other equipment is not within the scope of this document (see Section 3.3).

3.3 Boundaries of Components Addressed in This Study

The scope of this study is limited to MCCs, both ac and dc powered units, that contain a number of motor starters and other auxiliary devices. The study concentrates on MCCs in the 600-Vac and 250/125-Vdc classes, which typically supply single-phase, three-phase, and direct current motors ranging from fractional power ratings up through non-reversing motors rated at

149 kW [200 hp]. The mechanical boundaries include the steel cabinets housing the starter units (and other components) and the interconnecting devices between all vertical cabinets constituting the MCC. The power feed to the MCC cabinet, the load components (e.g., motor, motor operated valves, or transformers), and the power supply cables outside of the MCC are not within scope; however, the power cables within the wire troughs and channels of the MCC are within scope.

The overall boundary for components discussed in this document shall be the MCC itself; all components within the structural confines of an MCC are within scope. On a component basis, the following boundaries are set:

1. Structural Components — includes all structural components of the MCC including the metal housing, horizontal and vertical buses, stab disconnects, and removable buckets.

2. Molded-Case Circuit Breakers — includes the physical case of the breaker and internal subcomponents; also includes external electrical connections that are physically part of the breaker, as well as the external (cabinet mounted) breaker operating handle and related linkage.

3. Magnetic Starter/Contactor — includes contactor and starter subcomponents including the main contactor, interlock mechanism, and auxiliary contacts, as well as any other electrical connections that are part of the starter/contactor assembly itself.

4. Thermal Overload — includes typical stand-alone thermal overload units used for protecting motor circuits from overloads.

5. Relays — limited to timing or control relays that are part of MCCs and that are mounted within the confines of the MCC.

6. Control Transformer — limited to the physical transformer used to step down line voltages for control functions within MCCs.

7. Terminal Blocks — includes the base, cover (as applicable), and electrical terminals/hardware.

8. Control Wiring — includes control wiring between components within the bucket structure as well as main power wiring from the MCC bus structure to the motor starter in the bucket structure.

9. Fuses/Fuse Holders — includes the fuse, fuse holder assembly, as well as any associated electrical connections or indicating devices.

10. Switches — includes any locally mounted switches and their electrical connections.

3.4 Description of Components Evaluated

A motor control center is defined by IEEE Standard 649 as a floor-mounted assembly of one or more enclosed vertical sections having a common horizontal power bus and principally containing combination motor starter units. These units are mounted one above the other in vertical sections. The sections may incorporate vertical buses connected to the common power bus, thus extending the common power supply to the individual units. Units may also connect directly to the common power bus by suitable connections.[3.10]

Each MCC is complete and installed as a unit. Typically, electrical load centers, switchgear, power transformers, and other electrical power and control equipment are grouped in centralized areas of the plant. Because a typical nuclear plant may contain more than 1000 motors with voltage ratings of 600 volts or lower, 40 or more MCCs may be installed throughout the plant. In addition to motors, these centers provide controls for other electrical equipment, including inverters, lighting, and auxiliary devices. Spare cubicles are generally included within a given MCC to allow for future equipment additions or expansion.

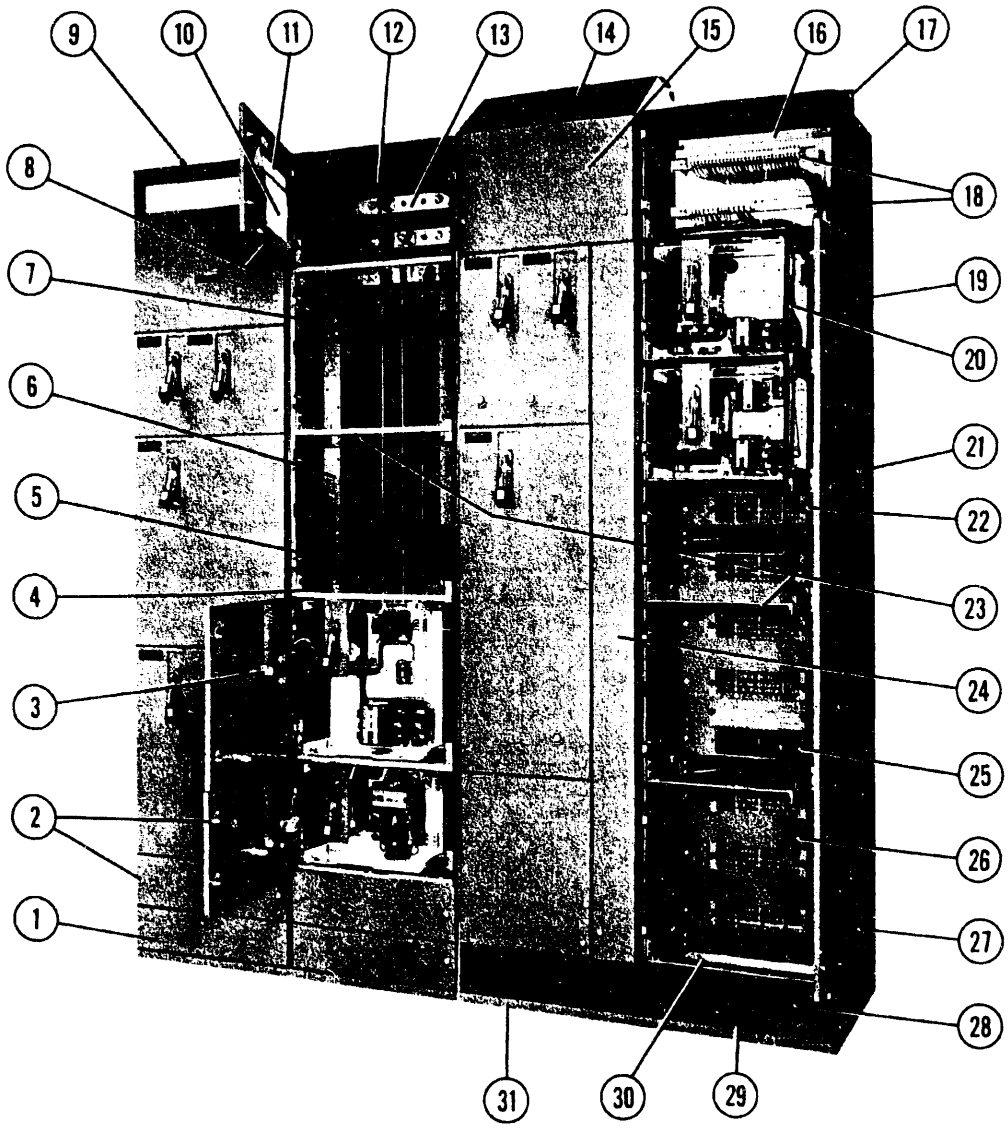
MCCs are low-voltage (600 volts or less) controllers whose functions are to control and protect plant loads. MCCs are used in a wide spectrum of applications, including pumps, fans, and motor-operated valves. The controller may also provide supplementary functions, such as operation at multiple speeds, reversing motor direction, or reducing levels of current/motor torque. MCCs can also provide control for auxiliary equipment such as brakes, clutches, distribution power panels, welding receptacles, solenoids, and space heaters. Although a motor controller is typically used to control a single motor, groups of motors can also be controlled. A basic description of each of the MCC components listed in Section 3.2 follows.

Motor control centers are defined in NEMA Standard ICS 2-1983, Section 322[3.11] based on their class as follows:

1. Class I - Class I motor control centers consist of a mechanical grouping of combination motor control, feeder tap assemblies, and other units arranged in a convenient assembly. They include connections from the common horizontal power bus. They do not include interwiring or interlocking between units or to remote devices and do not include system engineering.

2. Class II - Class II motor control centers consist of a grouping of combination motor control, feeder tap assemblies, and other units designed to form a complete control system. They include electrical interlocking and interwiring between units and to remote devices, including connection to the common power bus.

Within each class of MCC, several distinct types are manufactured; these types can generally be differentiated based on their individual features. For example, terminal boards and/or wiring may or may not be provided depending upon the Type (A, B, or C) of Class I MCC[3.12] procured. Figure 3-1 shows a typical motor control center.



NOMENCLATURE

1. Bottom Front Plate
2. ¼ Turn Latch Assembly
3. Door Interlock
4. Unit Support Bracket
5. Vertical Bus Bar
6. Vertical "U" Channel
7. Vertical Bus Brace
8. Diagram Pocket
9. Lifting Eye Bolt
10. Heater Coil Selection Table
11. Instruction Manual
12. Horizontal Bus Support
13. Horizontal Bus
14. Roof Plate
15. Top Front Plate
16. Horizontal Bus Barrier
17. Lifting Bracket
18. Terminal Block and Channel
19. Top Side Cover Plate
20. Vertical Door Strip
21. Right Hand Side Frame
22. Stab Hole Cover
23. Horizontal Cross Channel (16" or 20")
24. Vertical Wireway Door
25. Stab-In Opening
26. Vertical Bus Cover
27. Bottom Side Cover Plate
28. Bottom Plates
29. Wire Harness Clamp
30. Ground Bus
31. Front Sill

Figure 3-1. Typical Motor Control Center (MCC).[3.13]

3.4.1 Description of Predominant Types of Equipment in Grouping

3.4.1.1 Motor Control Center Structural Components (Including Metal Housing, Bus Structure, Terminals, and Disconnects)

An MCC is a group of combination starters, controllers, and protective devices mounted in free-standing cubicles. Vertical cubicles can be joined together and electrically connected to form a continuous assembly. A common horizontal bus runs throughout the top of each section. Each section has a separate vertical bus to which the control units and other components are connected. Individual "control units" are housed in separate metal, enclosed compartments, each with its own door. Seismic braces and bolts can be used to stiffen the sections and overall structure.

The typical vertical section of an MCC enclosure is 229 cm [90 inches] high, 51 cm [20 inches] wide, and 36 to 51 cm [14 to 20 inches] deep. Individual control units vary in height, depending on size. Generally, they are standard depth, permitting front only or back-to-back arrangement of units in the 51-cm- [20-inch-] deep section. Each vertical section typically has approximately 183 cm [72 inches] of control unit mounting space, enabling the use of up to six NEMA size 1 combination starter units. Sections are fabricated from sheet steel, shaped, and reinforced to form a rigid enclosed structure in single or multiple section lineups.

Power is typically distributed in an MCC through a system of horizontal and vertical buses. A main horizontal bus is generally located at the top of the section and carries power from the source to the MCC. The main horizontal bus may be secured to fiberglass-reinforced plastic bus supports by carriage bolts that are, in turn, secured to the top horizontal channel and a horizontal angle bar used specifically for locating the main bus. The bus supports are typically non-creeping and/or non-hygroscopic and comply with appropriate industry flammability standards.

The vertical bus assembly is often a "sandwich" of a combination of organic materials (such as polyester and fiberglass) enclosing the three-phase bus work. This assembly is usually held together using threaded fasteners, and may have steel banding (when required for higher levels of short-circuit withstand capability). The assembly is bolted to plates on each side, and the vertical bus/plate assembly is riveted or bolted to the enclosure side channels for support. The vertical bus is also usually bolted to the main bus. The ground bus and neutral bus, when required, are generally installed at the bottom of the enclosure in the horizontal wireway or trough. Space heaters can be installed in this area when required by the individual application.

Power is usually distributed from the horizontal bus to one or more vertical buses, one per MCC section, for use by each motor control module. The vertical bus may be sized to carry varying currents, depending on the application (usually 300 to 600 amperes), and is attached to the main horizontal bus. Main horizontal bus bars are typically sized for currents ranging from 600 to 2000 amperes. Horizontal and vertical bus bars are generally made of tin-plated aluminum or copper (with copper being used in nuclear plant applications).

To isolate the buses from the wiring compartments, doors can be provided in small channel guides in front of the bus work or around the wire channels. The vertical wireway is covered by hinged doors and is adjacent to each vertical unit compartment. It provides space for control and load wiring from individual units to the horizontal wireway and outgoing conduit or cable trays. This wireway can be common to the components on either side of the compartment or may service only a specific vertical line of compartments. The wireways are typically free of energized electrical equipment and are provided with cable tie straps for supporting wire bundles and cables.

As indicated above, MCC units contain motor control and distribution components. Each unit generally consists of a "C" shaped case with upper and lower barrier plates and a component mounting panel. The upper and lower barrier plates are the means of isolating the cubicle from units mounted directly above and below in the structure. These barrier plates also provide the mounting tabs for unit support brackets, latches, and lifting handles for unit removal. These assemblies (commonly referred to as "buckets") can be removed from and reinstalled into the MCC enclosure with minimal difficulty. The component mounting panel carries the motor starter, distribution, and other electrical components. The mounting panels generally vary in height from 30.5 to 182.9 cm [12 to 72 inches], depending upon the load the unit is servicing.

The component mounting panels are also equipped with stabs that engage the vertical bus bar (i.e., the starter unit has self-aligning stabs on the rear of each pan unit). The stabs are usually made from hard, tempered copper alloy and provide multi-point contact when engaged onto the vertical bus. In addition, they are designed to increase contact pressure on the vertical bus during a high current surge. Stabs provide the MCC with disconnect capability, which facilitates maintenance and component removal. The insulator material, a molded glass-reinforced resin, is used for its high dielectric and impact strengths, tracking resistance, and low moisture absorption.

Mechanical interlocks may also be provided within the MCC to ensure that only the circuit breaker with the correct voltage, current, and interrupting ratings for the MCC is inserted into the MCC compartment. Typical MCC safety and interlocking features include:

1. Unit doors cannot be closed unless the unit is fully inserted.

2. A test position is provided for the unit supported in the structure but disengaged from the bus. Padlocking is possible in this position.

3. Handles are provided on both top and bottom barrier plates to facilitate unit handling.

4. Doors are equipped with a mechanical interlock to prevent the door from being inadvertently opened when the unit is energized.

[3.12, 3.14, 3.15, 3.16, 3.17, 3.18, 3.19, 3.20, 3.21, 3.22, 3.23]

3.4.1.2 Molded-Case Circuit Breakers

A circuit breaker is defined in NEMA standards as a device designed to open and close a circuit by non-automatic means, and to open the circuit automatically on a pre-determined overcurrent, without damage to itself, when properly applied within its rating.[3.24, 3.25] The circuit breakers installed in MCCs are of the molded-case type. Molded-case circuit breakers (MCCBs) are low-voltage circuit breakers assembled as an integral unit into an enclosed housing of molded insulating materials. MCCBs protect connected equipment (in low-voltage distribution systems) against fault current and overload in certain applications. Figure 3-2 shows a typical MCCB and its internal components.

MCCBs can perform two functions: (1) a manual switching operation to open and close a circuit by means of a toggle handle and (2) an automatic opening of the circuit under sustained short-circuit or overload conditions.

The primary components in an MCCB are as follows:

Molded Case (Frame)

The function of the molded case is to provide an insulated housing and structural support to all of the circuit components and to ensure that the circuit breaker can withstand and interrupt an electrical fault. The cases are typically molded from phenolic or glass polyester material that combines ruggedness and high dielectric strength in a compact design. The case must be strong enough to withstand mechanical forces caused by fault currents, thermal stresses produced during normal operation and fault current interruption, and internal pressure caused by gases produced during arcing.

For a given manufacturer, each different size and type of molded cases is assigned a frame designation to facilitate identification. For example, frames are identified by letters such as EB, JB, or LB. This frame identification refers to a number of important characteristics of the breaker, including the maximum allowable voltage and current, interrupting capacity, and the physical dimensions of the molded case. Each breaker manufacturer uses a somewhat different identification system because of differences in the breaker's physical characteristics. For example, a 400-ampere, 600-volt breaker supplied from two different manufacturers may have different physical dimensions and interrupting capacity.

Operating Mechanism

The operating mechanism provides a means of manually opening and closing the breaker contacts. During closing, the operating mechanism charges a spring that later provides the necessary force for quick opening of the main contacts, initiated either manually or by an automatic trip. The operating mechanism contains an external breaker handle whose position indicates the contact status: closed (ON), open (OFF), and tripped. The breaker is in the tripped condition when the handle is approximately midway between ON and OFF. MCCBs are designed trip-free, meaning the breaker will trip under overload or short-circuit conditions even if the breaker handle is held in the ON position. To restore service after the breaker trips, the breaker handle must first be moved from the tripped position to OFF (to reset the mechanism), and then to ON. Some MCCBs include a push-to-trip mechanism (in addition to the operating handle) that provides a manual means of tripping the circuit breaker. When the push-to-trip button is pressed, a plunger rotates the trip bar, causing the breaker to trip.

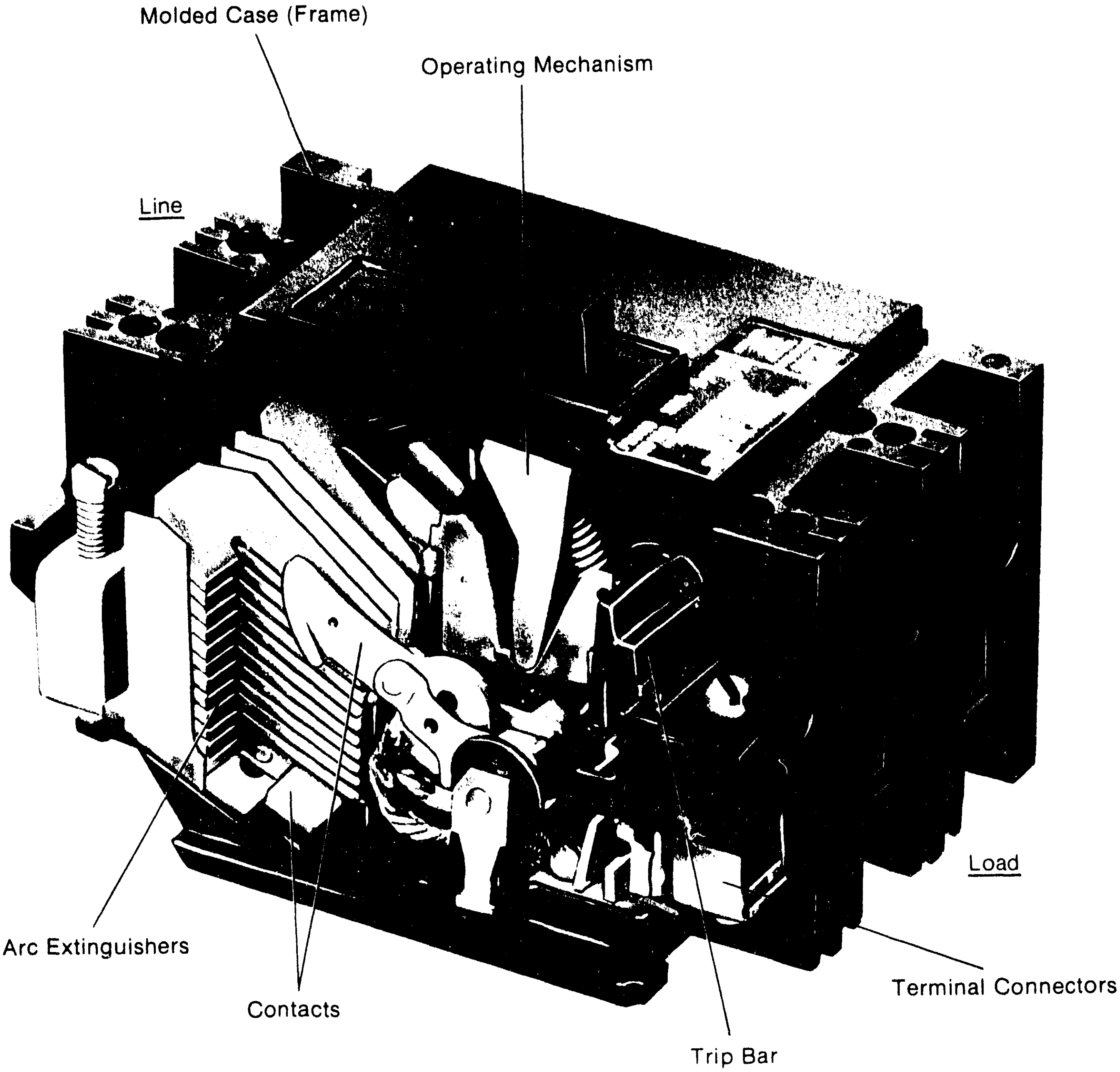


Figure 3-2. Molded-Case Circuit Breaker (MCCB) and Internals.[3.26]

Many MCC breakers are also equipped with external operating handles (and linkages); these allow operation of the breaker by means of some device mounted externally on the MCC (such as a rotary handle). These devices simply translate the rotary motion imparted to the external handle into linear force on the MCCB handle (described in the preceding paragraph) and allow operation of the MCCB as a switch without opening the MCC cubicle door.

Breaker Contacts

The breaker contacts function to physically make or break the power circuit. During normal operations, they are closed and allow current to flow. Under faulted or overload conditions, they open to provide current interruption. Typically, the contacts are opened by spring force, and are equipped with a toggle mechanism that causes the contacts to make and break quickly. Hence, the speed with which the contacts open or close is independent of the speed at which the breaker handle is operated.

The contacts play a critical role in the design of a breaker. In the closed position, the contacts must have a low resistance, allowing current to be conducted without overheating or excessive voltage drop. When the contacts are opened, an electrical arc forms and the contacts must withstand these electrical arcs. An ideal contact has a low resistance when closed, high immunity to damage by arcs, and high structural strength to withstand the mechanical impact of closing. A significant objective of breaker design is the protection of the surfaces of the contacts from erosion caused by arcing and damage caused by mechanical operation. The closing operation should also cause a wiping/cleaning action as the contacts meet; this helps clean the contacts and maintain low contact resistance.

Arc Extinguishers

Arc extinguishers redirect and quench arcs formed between breaker contacts during current interruption. The basic arc extinguishing mechanism consists of an arc-chute. Arc extinguishers are designed to channel the arc away from the mating surface of the contacts and into the arc-chute, where it is safely extinguished, preventing contact damage. The ability of the arc-chute to contain the arc being dissipated greatly reduces the possibility of a phase-to-phase or phase-to-ground fault, especially under the extreme conditions resulting from fault current interruption.

The arc extinguisher consists of closely spaced steel plates that are insulated from one another and function to cool and dissipate the arc and allow gas to deionize. The breaker contact surfaces are usually made of an alloy of a high conductivity material, such as silver or tungsten, which is resistant to damage by the high temperatures that may accompany an arc. Upon the opening of the breaker contacts, the air space between the contact faces is ionized, and current (the arc) continues flowing. The arc current then produces a localized magnetic field that pulls the arc into the steel plates where it is divided and cooled.

Two naturally occurring phenomena, the thermal effect and the presence of a magnetic field, aid in current interruption. The thermal effect, which occurs because of the higher local temperatures of the arc, refers to the establishment of an upward air flow through the arc-chute. As the warm, ionized air around the arc rises, it is replaced by cooler air flow through the arc-chute. This cool, un-ionized air helps to cool and weaken the arc and move it into the arc-chute.[3.27]

Trip Elements

Trip elements function to automatically trip the circuit breaker in the event of circuit overloads, component short circuits, or ground faults. Current interruption is accomplished using either a thermal (bimetallic), magnetic (electromagnet), thermal-magnetic (a combination of both thermal and magnetic), hydraulic-magnetic, or solid-state device.

Thermal trip or time delay trip protection opens the breaker in the event of sustained overcurrent conditions. The trip action is achieved through the use of a bimetallic device, through which current flows. The temperature of the bimetallic trip device increases proportional to the level of current flowing through the circuit breaker. As the current increases, the different thermal expansion coefficients of the constituent metals cause the bimetallic strip to bend until it strikes the trip latch. By virtue of the fact that the temperature change of the metals does not occur instantaneously, a time delay between the increased current and breaker trip exists. This time delay is inversely proportional to the current passing through the circuit breaker. Therefore, the trip device will not react to current transients of relatively short duration.

Although thermal overload protection may be associated with MCCBs in some applications, the majority of MCCs use separate thermal overload devices to protect against overload conditions. The principle behind these devices is described in Section 3.4.1.4.

Magnetic trips (also known as instantaneous trips) are actuated without any appreciable time delay. They function in the event of a large current caused by short circuit or fault. When a short circuit occurs, the fault current passing through the circuit breaker generates a magnetic field that attracts the magnetic trip device, thus actuating the breaker trip latch. This process typically occurs within one cycle of the electrical power source and, thus, is considered instantaneous.

Magnetic trip elements, depending on the breaker type and frame size, are either fixed or adjustable. For example, most thermal-magnetic breakers on MCCBs rated 250 amperes and above have adjustable magnetic trips. Adjustable magnetic trips are calibrated at the factory for a specific range. Adjustment knobs located on the front of the trip unit can be used to set the breaker to specific requirements. The adjustment typically varies the size of the air gap between the magnetic trip coil and the armature; this gap, in turn, determines the magnetic trip current setting of the breaker.

Molded-case circuit breakers containing only an instantaneous overcurrent trip unit are sometimes used in conjunction with thermal overload units for motor circuit protection. This type of MCCB is often referred to as a motor circuit protector (MCP).

Thermal-magnetic trip devices are simply a combination of the thermal and magnetic devices described in the preceding paragraphs; these devices provide the benefits of both types of elements in one unit. Thermal-magnetic breakers can be used to provide overload and short circuit protection for non-motor branch circuits.

Hydraulic-magnetic devices generally use a solenoid coil surrounding a movable magnetic core that travels through a liquid fill; during normal operation, the magnetic flux produced by the coil is insufficient to move the core (because of a retarding spring). During overload or overcurrent conditions, however, the flux overcomes the spring force and moves the core at a speed controlled by the liquid (thereby inducing a time delay in the trip). When the core moves a sufficient distance, an armature piece is attracted to the core and the breaker trips. In some models, the time delay is removed, thereby producing an instantaneous trip.[3.28]

Solid-state (or electronic) devices differ considerably from the thermal/magnetic trip units in that no bimetallic strip or direct electromagnet is used to accomplish the trip function. Instead, a current transformer is generally used to sense the current through the breaker, and this transformer develops a signal proportional to the current level, which is then fed to a solid-state control unit that interprets the signal and produces an output signal depending on the required response. This output signal is then fed to an actuating device (such as a trip coil or solenoid) to accomplish the desired function. Typically, solid-state trip units such as this are inherently more accurate than their thermal or magnetic counterparts (approximately ±5% as opposed to ±20 to 25% for the thermal/magnetic units). Trip point stability (e.g., lack of drift) is also enhanced on the solid-state devices. Figure 3-3 shows a typical solid-state MCCB.

Some MCCBs (generally older models) are equipped with current-limiting fuses; these fuses provide high fault current protection similar to that of the magnetic trip unit described above. As with other multi-phase fuse applications, however, current-limiting fuses can not be reset (i.e., must be replaced after fuse failure) and are susceptible to single-phasing.

The major vendors of circuit breakers typically offer several different breaker frame sizes, each applicable to a particular range of operating current. Tripping devices with varying settings are then used within a frame size to provide flexibility. The standard thermal-magnetic circuit breaker used in non-motor applications has a non-adjustable short circuit magnetic trip. In contrast, magnetic-only circuit breakers designed for motor circuit applications are generally provided with adjustable short circuit magnetic trips allowing for accurately controlled short circuit protection.

Auxiliary Devices

Other devices often associated with the MCCB include the shunt trip device (coil) and the auxiliary contact mechanism. The shunt trip device is used to trip one or more MCCBs on command from a remote operating switch or button. This device is composed of a coil-type solenoid that actuates a portion of the internal breaker trip mechanism upon movement of the solenoid plunger. Auxiliary contacts (or switches) are used to provide remote indication, alarm, control, and interlocking functions; most auxiliary contact units are configured as either an "A" contact (contact open when breaker open or tripped), "B" contact (contact closed when breaker is open or tripped), or both (multiple contacts in one unit).[3.12, 3.24, 3.25, 3.26, 3.27, 3.28, 3.29, 3.30, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37, 3.38, 3.39]

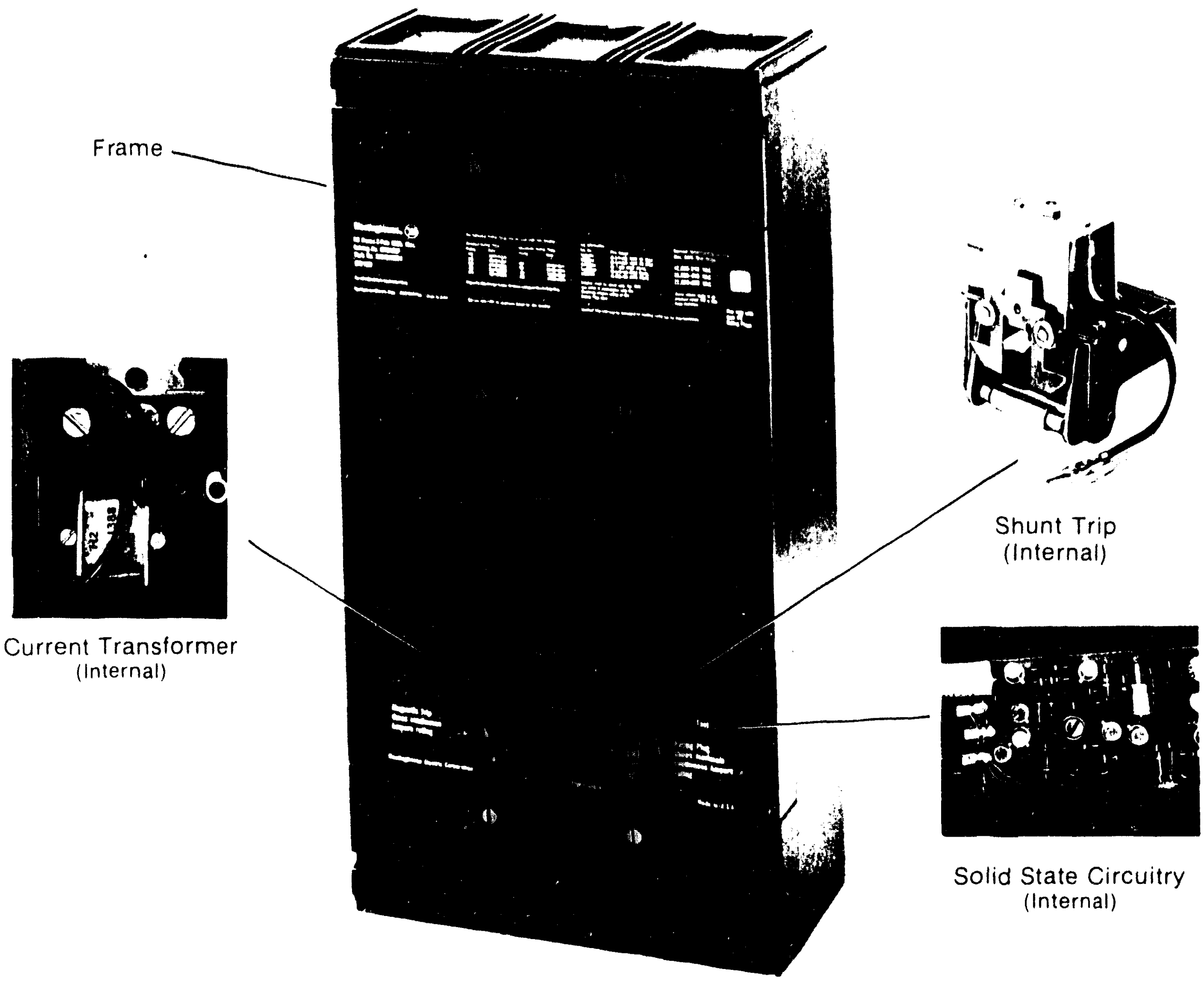


Figure 3-3. Solid-State MCCB.[3.26]

3.4.1.3 Magnetic Contactor/Starter

The terms "magnetic contactors" and "starter" are generally used interchangeably to describe devices used to provide power to and control of connected loads. The contactor provides the function of starting and stopping its load through a set of movable power contacts. A starter combines the functions of the contactor and thermal overload relays. Thermal overload devices are discussed in further detail in Section 3.4.1.4. Contactors, by themselves, are normally used for high current, non-motor loads where overload protection is not required. Starters, in contrast, are generally used for motor loads where overload protection is desired and not otherwise furnished by a separate device. Figure 3-4 shows a typical motor starter assembly.

A typical motor starter is connected between the power supply from a load center and the motor being controlled and protected. Figure 3-5 provides a wiring diagram of a single motor control unit. The complexity of the arrangement described increases as functions such as reversibility and speed control are added.

There are two basic categories of motor starters: manual and magnetic. The primary difference between a manual starter and a magnetic starter is the use of an electromagnet in the magnetic starter. In the magnetic starter, current flowing in the coil of the electromagnet induces a magnetic field that interacts with another ferro-magnetic material serving as an armature, or moving component. The armature is mechanically connected to a set of contacts such that when the armature is attracted to the magnet the contacts close to start the motor load. When the coil has been energized, and the armature has moved to the closed position, the controller is said to be "picked up." The manual starter, in contrast, uses some external manual force (such as that from a pushbutton) to close the contacts. In both types of starter, a "seal-in" circuit maintains the coil energized (and thus the contacts closed) after release of the actuating device (i.e., electromagnet or pushbutton). Manual starters are rarely used in MCCs and are generally not used in safety-related applications.

An important subcomponent of the magnet armature assembly in an alternating-current (ac) contactor is the shading coil. A shading coil is a single turn of conducting material (generally copper or aluminum) mounted on the face of the magnet assembly or armature. An alternating magnetic flux is produced in an ac contactor or relay; this occurs as the current applied to the coil varies in magnitude from zero to its maximum value. As the current approaches zero, the magnetic pull generated on the armature is reduced accordingly, and the armature will tend to open. As the magnitude of the current again increases, the force on the armature increases. This operation causes a characteristic humming noise in an ac device. With the presence of a shading coil, the alternating main magnetic flux will induce a current in the shading coil; this current sets up an auxiliary magnetic flux that is out of phase from the main flux. The auxiliary flux produces a magnetic force that is out of phase from the force produced by the main flux; this force helps keep the contacts engaged when the main flux falls to zero. Direct-current (dc) coils are not subject to a zero current condition; hence, dc devices do not exhibit the phenomenon described above, and do not need shading coils.

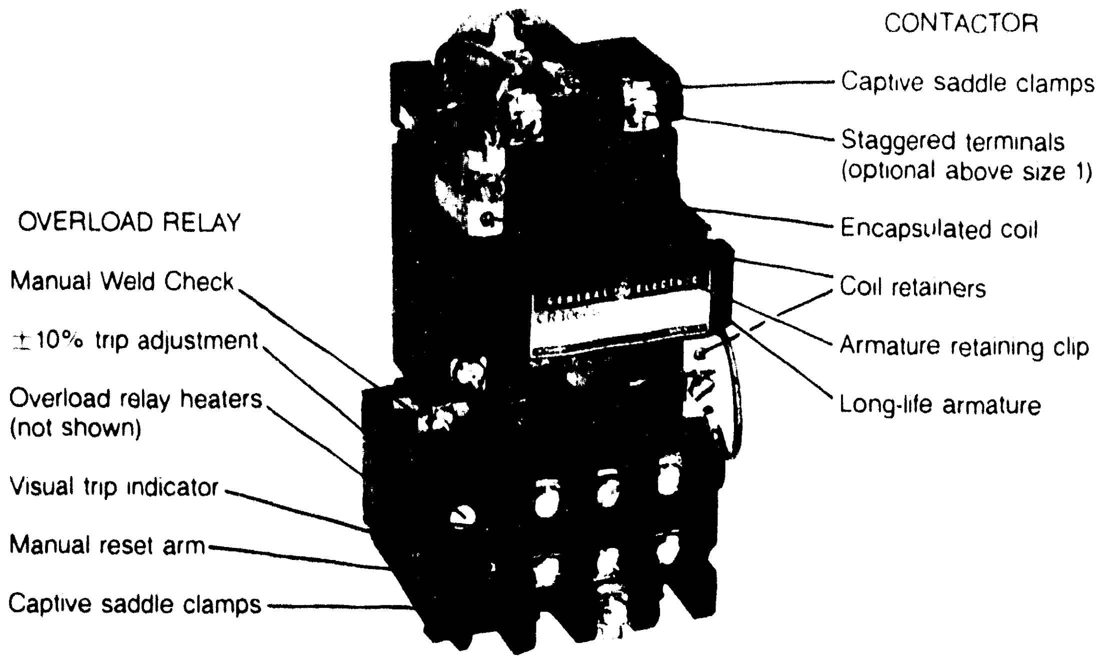


Figure 3-4. Typical Motor Starter (with Integral Overload Relay).[3.37]

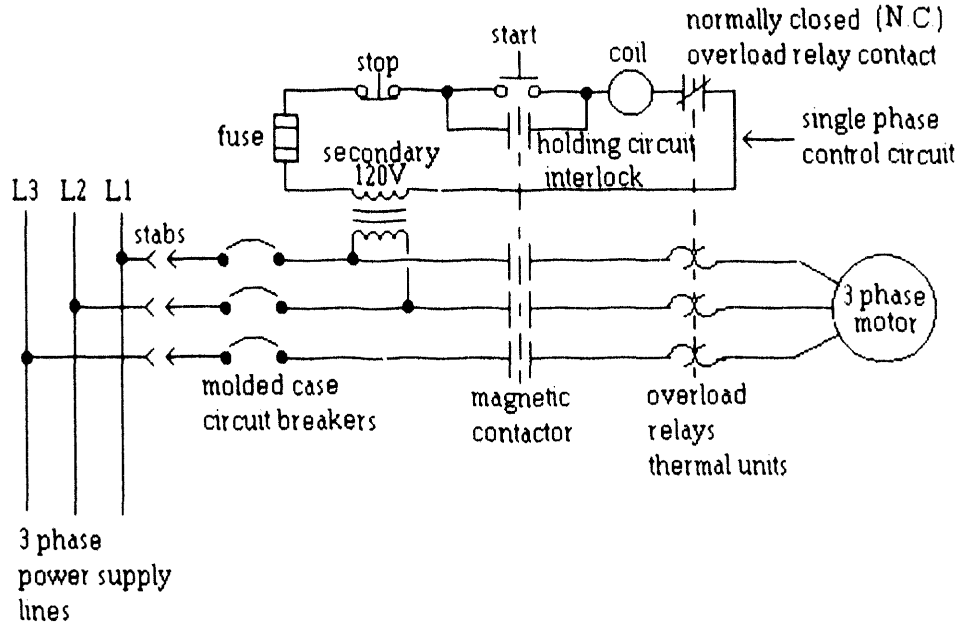


Figure 3-5. Typical Wiring Diagram of Motor Controller.

Power circuit contacts are used to supply and interrupt power to the motor load. The starter must be capable of carrying the full load current without exceeding the design temperature rise, as well as making and interrupting the motor circuit under locked rotor conditions. The physical characteristics of the starter (including its current carrying and interrupting capability) determine its NEMA size classification.

There are two types of contactors frequently used in motor starter design, the bell crank type and the horizontal action type. Both types operate on similar principles, using a magnet and coil arrangement to effect the closure of the contacts. The bell crank armature and magnet contactor assembly is unique in that it is designed to have a lower seal-in voltage than pick-up voltage, thus extending contact life and reducing contact damage under abnormal operating conditions. Simplified bell crank and horizontal action contactors are shown below in Figures 3-6 and 3-7, respectively.

The contactor coil consists of turns of insulated copper wire wound on a spool and protected by an epoxy molding. A ferrous armature (core) is acted upon by the coil; when the contactor is in the open position, an air gap exists between the armature and the coil assembly. Because of this air gap, the impedance of the coil is relatively low so that when the coils are energized a fairly high current is drawn. As the armature moves closer to the coil assembly, the air gap is reduced (and with it, the coil current), until the armature has reached the limit of its travel. The current generated during the initial inrush is approximately 6 to 10 times the current experienced with the armature at its travel limit. This ratio varies with differences in design. After the controller has been energized for some time, the coil will become hot. This will cause the coil current to fall to approximately 80% of its value when cold because of the increased resistance of the heated coil wire.

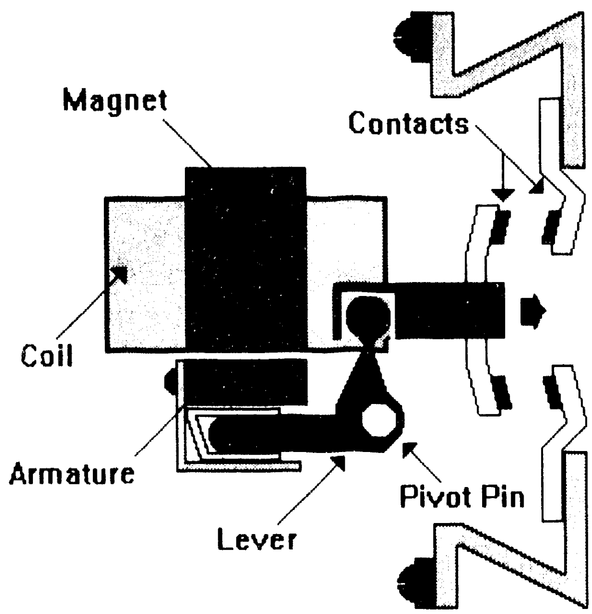


Figure 3-6. Bell Crank Type Magnetic Contactor.

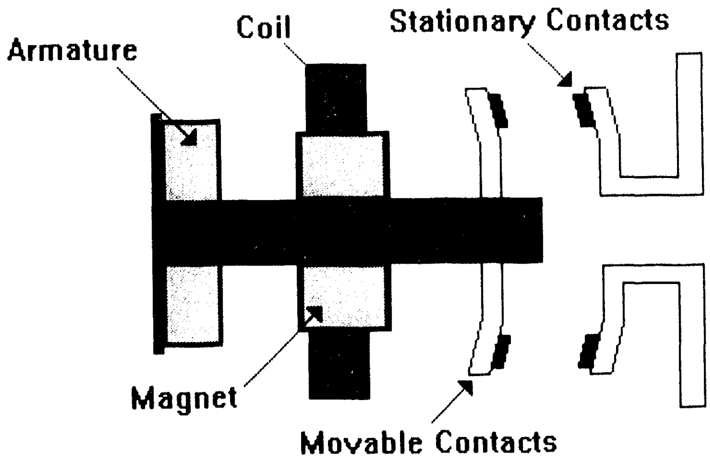


Figure 3-7. Horizontal Action Type Magnetic Contactor.

In addition, the changing magnetic fluxes produced by alternating currents induce electromagnetic forces in the ferrous core that, in turn, produce eddy currents that circulate in the core. Eddy current losses and heating effects are reduced by laminating the magnetic assembly and armature. The faces of the armature and the magnet assembly generally have very close tolerances to provide the maximum force to close the contacts and help ensure quiet operation. [3.12, 3.29, 3.36, 3.37, 3.39, 3.40, 3.41, 3.42, 3.43, 3.44, 3.45, 3.46]

3.4.1.4 Thermal Overload Relays

A large portion of MCCs serve motor loads used in various plant systems. A majority of these motor loads have separate overload devices for protection of the individual motors from currents in excess of the rated current. In general, there are two types of overcurrent conditions against which the MCC is designed to protect: electrical faults and overload currents. Electrical faults are characterized by nearly instantaneous increases in current, usually to extremely high levels. As discussed in Section 3.4.1.2 above, these transients are expected to be terminated by the MCCB. Overload conditions, in contrast, are characterized by currents much closer to (yet still above) the design maximum rating of the connected load that potentially could exist for extended periods of time. Protective devices used to mitigate the effects of an overload condition must not trip upon the inrush starting current of the load; for a motor, these currents can be many times the normal full-load running current and last several seconds.[3.12] At the same time, the device must provide protection for small overloads (slightly above full load current) lasting for a lengthy period. Thermal overload devices ("thermal overloads") are designed to satisfy these requirements. Figure 3-4 shows a typical thermal overload relay/motor starter arrangement.

Overload relays can withstand repeated trip and reset cycles, and possess the desirable trait of an inverse time characteristic (i.e., higher current results in a shorter time to trip) that allows them to perform the required function of a thermal overload device. The majority of overload relays in use today incorporate thermal devices that rely on the heat generated by the current passing through the circuit during an overcurrent condition to trip.

Overload relay characteristics closely resemble those of the motor heating curve; line current drawn by the load will be directly proportional to the heat dissipated by the heater element in the overload relay. The overload relay trip is designed to disconnect the motor from its line source just before motor overheating occurs for all values of load current. In magnetic starters, an overload opens a set of contacts within the overload device itself. These contacts are wired in series with the starter coil in the control circuit of the magnetic starter. Breaking the coil circuit causes the starter contacts to open, disconnecting the motor from the line. In a manual starter, an overload generally trips a mechanical latch that causes the starter contact to open, disconnecting the motor from the line. Increasing overload current results in shortening the time until the overload relay trips; this is characteristic of an inverse time delay.

Thermal overload relays can be classified as either melting-alloy or bimetallic. Magnetic overload relays operate only in response to the increased magnetic field generated during current excesses, and are not significantly affected by temperature. These magnetic devices are not as common as the melting-alloy or bimetallic thermal overload relays. Melting-alloy, bimetallic, and magnetic overload relays are discussed individually in the following paragraphs.

Melting-Alloy Thermal Overload Relay

Melting-alloy thermal overload relays, also referred to as solder pot relays, consist of a heater element, eutectic alloy, alloy pot, ratchet wheel, pawl, spring, and contacts (see Figure 3-8).[3.12] The line current drawn by the load is directly proportional to the heat dissipated by the heater and acting upon the eutectic alloy. The spring-loaded pawl is held in place by the ratchet wheel securing the pawl and keeping the contacts shut. The shaft of the ratchet wheel is normally secured by the solidified eutectic alloy, and the contacts remain in a closed position. Should the current drawn by the motor become excessive for a sufficient period of time, the heat dissipated by the heater will melt the eutectic alloy, allowing the ratchet wheel to rotate. The spring-loaded pawl is then free to move, allowing the contacts to open, which, in turn, de-energizes the control circuit and the starter. When the alloy has cooled and subsequently hardened, the unit can be manually reset.

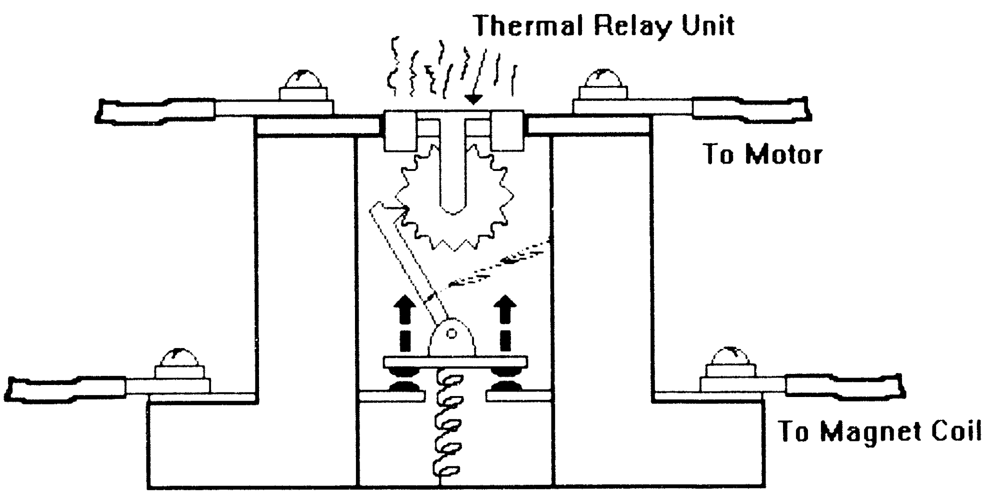


Figure 3-8. Melting Alloy Thermal Overload Relay.

Bimetallic Thermal Overload Relay

Bimetallic relays use a bimetallic strip (as opposed to a eutectic alloy) to sense heat as current is increased. Figure 3-9 illustrates the operating principle of a bimetallic overload relay. The bimetallic strip is designed to flex a predetermined amount at a specific temperature because of the use of two metals with differing thermal expansion coefficients. The temperature is chosen as the temperature corresponding to the point at which the motor must be disconnected from the line to avoid damage to the motor insulation. When this temperature is reached, the bimetal strip bends, thereby applying force to the contact mechanism, which, in turn, opens the contacts and disconnects the motor.

Bimetallic relays offer both advantages and disadvantages when compared with the melting alloy relays. Bimetallic units have the ability to be converted from manual reset to automatic reset. The automatic reset feature is not normally desirable, as it most often leaves the root cause of the problem unsolved. The automatic reset function could potentially allow the motor to heat up, be disconnected, cool off, and restart repetitively until the motor eventually fails (assuming no operator intervention). However, the automatic reset does have a place in protecting a motor that is isolated or where it would be more desirable to allow the motor to deteriorate rather than immediately lose the function that the motor provides.[3.12]

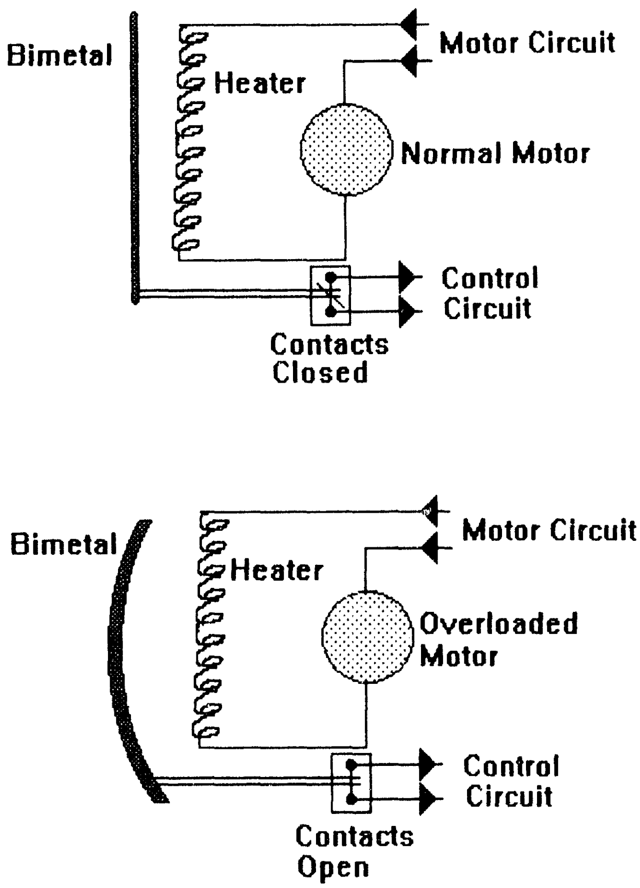


Figure 3-9. Bimetallic Thermal Overload Relay.

Another desirable feature of bimetallic relays is the ability to adjust the trip point. This feature allows the trip point to be set from approximately 85% to 115% of the rated trip current. Most bimetallic overload relays offer the added flexibility of removable, interchangeable heater elements; this allows for easy changing of the current rating without removing the entire thermal relay.

Bimetallic thermal elements may be modified so that they automatically compensate for variations in ambient temperature. Compensation is obtained by using an additional bimetal strip that counteracts the effect of ambient temperature changes on the overload bimetal. This temperature compensated trip provides a near constant current rating over a wide range of temperatures and may be useful in situations where the motor and its associated overload relay are in different areas of the plant, as is often the case.

Magnetic Overload Relay

The magnetic overload relay does not rely on the heating effects of an overload condition, but instead makes use of the magnetic field established when a current is carried through a conductor. A magnetic overload relay generally has a movable magnetic core inside a coil that carries the motor current. The flux established inside the coil exerts a force that pulls the core longitudinally with respect to the coil. If the core moves a sufficient distance, it trips a set of contacts that ultimately disconnect the load. Core movement is slowed by a piston contained in an oil-filled dashpot; this dashpot acts as a dampener to allow for fluctuations of relatively short duration without tripping the device. Tripping current is adjusted by changing the core's position on a threaded rod, whereas the tripping time is varied by uncovering oil bypass holes in the piston. Because the magnetic core relay has adjustable trip levels and times, it is sometimes used to protect motors having long accelerating times or unusual duty cycles. The magnetic overload relay is similar to magnetic instantaneous trips found in MCCBs except the instantaneous trip device does not have an oil-filled dashpot.[3.12, 3.29, 3.30, 3.36, 3.37, 3.39, 3.40, 3.41, 3.42, 3.47]

3.4.1.5 Miscellaneous Relays

A relay is an electromagnetic device whose contacts are used in the control circuits of magnetic starters, contactors, solenoids, timers, and other relays. Figure 3-10 shows a typical control relay. Relays are mainly used for low-current control applications and function in the same manner as contactors, with the exception that contactors are for power applications. Relays are generally used to amplify the contact capability or multiply the switching functions of a remote switch or sensing device. The following examples illustrate a few of the functions for which relays may be used within an MCC.

Figures 3-11 and 3-12 demonstrate how a relay amplifies contact capacity. Figure 3-11 represents a current amplification. Relay and starter coil voltages are the same (220 volts), but the ampere rating of the temperature switch is too low to handle the current drawn by the starter coil (M). A relay is interposed between the temperature switch and starter coil. The current drawn by the relay coil is within the rating of the temperature switch, and the relay contact has a rating adequate for the current drawn by the starter coil.

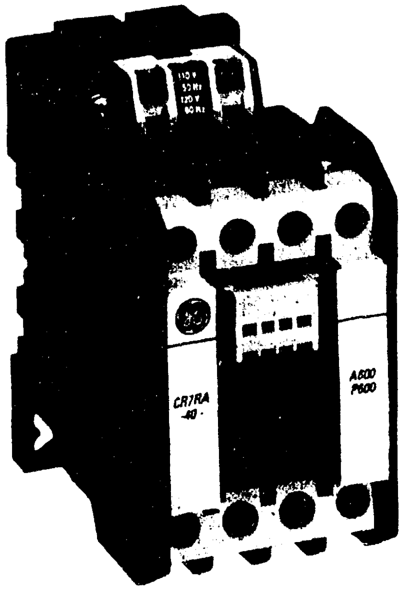


Figure 3-10. Typical Control Relay.[3.37]

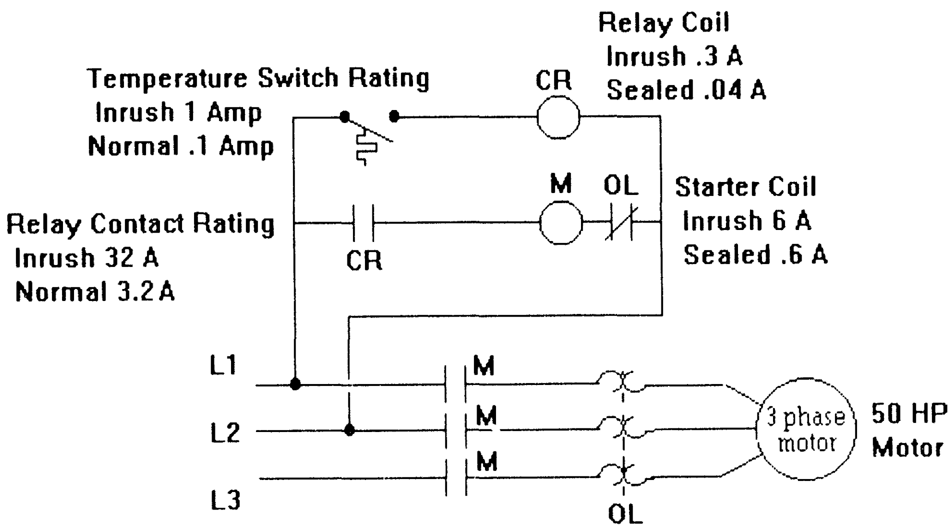


Figure 3-11. Relay Used for Current Amplification.

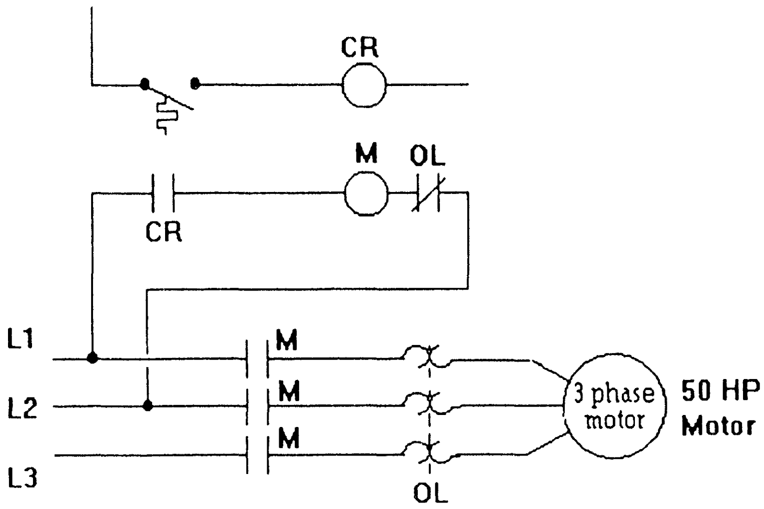


Figure 3-12. Relay Used in Voltage Interface.

Figure 3-12 represents a voltage change for interfacing two different control voltages. A condition may exist in which the voltage rating of the temperature switch is too low to permit its direct use in a starter control circuit operating at some higher voltage. In this application, the coil of the interposing relay and the pilot device are wired to a low-voltage source of power compatible with the rating of the pilot device. The relay contact, with its higher voltage rating, is then used to control the operation of the starter.

Figure 3-13 represents another use of relays, which is to multiply the switching functions of a pilot device with a single or limited number of contacts. In the circuit shown, a single pole pushbutton contact can, through the use of an interposing 6-pole relay, control the operation of a number of different loads such as a starter, contactor, solenoid, and timing relay. Relays are commonly used in complex controllers to provide the logic to set up and initiate the proper sequencing and control of interrelated operations.

Relays used in MCC applications may fulfill a variety of different functions, such as timing or load control. They differ in voltage ratings (150, 300, or 600 volts, for example), basic configuration, number of contacts, contact convertability, physical size, and in attachments to provide special functions (such as mechanical latching).[3.12, 3.27, 3.29, 3.30, 3.36, 3.37, 3.39, 3.40, 3.41, 3.48]

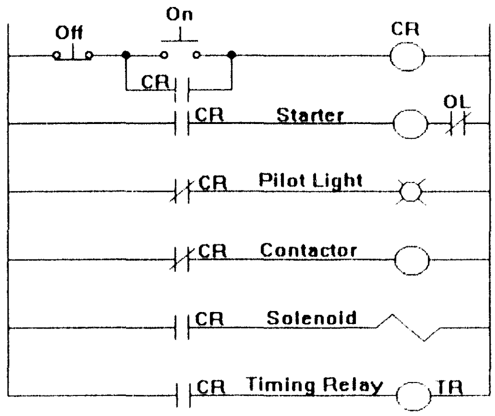


Figure 3-13. Relay Used to Multiply Switching Functions.

3.4.1.6 Control Transformers

In ac MCCs, power for auxiliary functions associated with the control circuits (e.g., indicating lamps and solenoids) and other functions (such as contactor energization) may be obtained from the input line voltage present at the starter or from other sources external to the MCC. Generally, the use of a control voltage lower than 480 or 600 Vac is advisable. To generate control power at the reduced voltages, control power transformers are used within the MCC. The line voltage of the power supplied to the motor determines the required primary rating of the control power transformer. The secondary of the transformer must be rated to provide the desired control-circuit voltage and to match the voltage of the contactor operating coil. In addition, the continuous secondary current rating of the transformer must be sufficient to sustain both the magnetizing current of the operating coil and the inrush current generated during initial coil energization. Standard control power transformers have a 120-volt secondary, which provides a good balance between reliability and safety. As an industry standard, the minimum size for control power transformers is generally two and one-half times the contactor sealed volt/ampere rating. Usually, the transformers are larger than this to allow for the flexibility of added auxiliary relays and devices.

Control power transformers may be furnished for each individual starter or, alternatively, one large control power transformer may provide control power to multiple starters. Although both schemes are satisfactory, individual control power transformers provide greater system reliability. Transformers can be obtained with fused or otherwise protected secondaries to meet code requirements on control-circuit overcurrent protection. If a single large control power transformer fails or a protective fuse blows, the loads served by that unit are accordingly de-energized. With individual control power transformers, only one starter would be affected by a single fault.[3.49]

[3.12, 3.29, 3.36, 3.37, 3.39, 3.40, 3.41]

3.4.1.7 Terminal Blocks

Terminal blocks are often used to organize and simplify connections within an MCC. Terminal blocks are devices that are mounted in fixed positions inside the MCC where a number of wire connections must be made. They are typical components found in MCCs even for the simplest control circuitry. Terminal blocks simplify the connection of wires from different components. Because of their fixed position, controlled grouping and routing of wires inside MCC enclosures is possible. This orderly layout permits rapid, accurate wire installation and speeds maintenance and troubleshooting operations.

The common one-piece terminal block usually comes in standard units of 2, 4, 6, 8, or 12 terminals on a single base. The terminals can be located on a rigid insulating member or between barriers. The barriers may be open (allowing easy access to the contacts) or closed (protecting the contacts from external effects). The terminals themselves are made of conducting material and generally use a post/nut type arrangement for fastening the wire termination to the terminal. Terminal blocks may also include other optional attachments such as protective covers and fuse holders.

Another common terminal block configuration uses a sliding metal link (hence the name sliding link terminal block) that allows easy wire installation and electrical disconnection of the two posts during testing (thereby avoiding wire removal). A clamp-and-bolt arrangement is used to form the sliding link between the two posts. Other features are similar to those of the one-piece terminal blocks described above.

[3.12, 3.29, 3.36, 3.37, 3.39, 3.40, 3.41]

3.4.1.8 Control Wiring

Control wiring is used in MCCs to interconnect various electrical components within the starter cubicle and MCC structure. Control wiring used in MCCs is primarily routed via troughs or bundles between terminal blocks, although it may also enter and/or exit the MCC or connect components directly. Wiring used in MCCs is typically rated at 600 Vac, although control circuits and devices usually operate at reduced voltages by virtue of the control power transformer(s). It may have single- or multi-stranded conductors, and is generally insulated with a suitable organic material such as ethylene propylene rubber or cross-linked polyethylene. Control wiring may vary in size and type within a given MCC or even within a given cubicle. It may also be equipped with varying types of terminations (such as crimped lugs or plug-in style connectors).

[3.12, 3.29, 3.36, 3.37, 3.39, 3.40, 3.41]

3.4.1.9 Fuses and Fuse Holders

Fuses are among the oldest types of overcurrent protective devices and are used for some applications instead of MCCBs. Current flowing through the fuse generates heat proportional to the current; at a specified current, the fusible link (which may exist in a variety of configurations, such as silver wires or eutectic alloy solder joints) will melt and open the conducting path. This fusible link cannot be reset; hence, the affected fuse must be replaced prior to resuming operation. Fuses are typically used in units with low current ratings, whereas MCCBs are preferred on higher current rating circuits.

Fuses are used in MCCs to provide protection of either power or control circuit components. Power fuses are employed in the motor power path (one per phase in ac systems) as protection against overcurrent conditions. Control fuses, on the other hand, are installed between the control power source (which may be the control power transformer or some external source) and the control components; these fuses are designed to protect the control components from overcurrent conditions. Power fuses usually have substantially higher voltage and current ratings than control fuses. Current-limiting fuses are sometimes used to protect MCCs from very high fault current.

It should be noted that circuit breakers have an advantage over fusible elements; a fault on one pole of a multi-pole breaker actuates a common trip bar that opens all poles simultaneously, thus avoiding single phasing a motor circuit (as could occur in a fusible device). Some fuse assemblies, however, may be equipped with an anti-phasing device to eliminate this problem.

Fuse holders and clips are devices used to support, protect, and electrically connect the fuses to the circuit or device being protected. Fuse holders (sometimes called carriages) are usually located in conspicuous, easily accessible locations to allow a failed device to be readily identified and replaced. In addition, many fuse holders will be equipped with visual inspection ports or indicating lights to alert the operator to the fuse failure. Many different configurations of fuse holders exist: some employ simple metal spring clips to allow easy insertion/removal of the fuse and to ensure proper contact pressure; still others use a cylindrical holder with a screw-on cap. Contact surfaces may be coated with a conductive, corrosion-resistant plating to preclude oxidation and corrosion of the surfaces and, thereby, potential interruption of the current path.

[3.12, 3.29, 3.36, 3.37, 3.39, 3.40, 3.41]

3.4.1.10 Switches

Electrical switches may be used on MCCs for a variety of functions ranging from space heater control to metering functions. These components come in many different configurations (e.g., size, ampere rating, number of contacts) based on their function. Generally, the failure of these components will not preclude the fulfillment of a required MCC function; hence, they are considered non-significant. Switch failures are included in the historical analysis (Section 3.6) for illustrative purposes.

3.4.2 Discussion of Manufacturers' Design Differences

There are numerous types of MCCs in existence, many of which are still in commercial production today. Vendors for MCCs and their components are listed in Section 2.3 of this guideline. Throughout the nuclear industry, different model lines from the various manufacturers (such as the GE 7700, ITE 9600, and Westinghouse Type W) have been used, depending upon the time at which the nuclear facility was constructed. Furthermore, several different configurations of a given MCC may exist, based on the components and options installed and the loads serviced. Hence, a potentially large number of component combinations and MCC configurations are in use in nuclear plants today.

Despite the significant number of different MCCs/components in use, there is a large degree of similarity among them. For example, although the external appearance, features (such as the operating handle or locking devices) and installed components used in these MCCs vary from one manufacturer to another, their internal construction (buses, terminals, etc.) and structural design are largely consistent. Additionally, MCC dimensions are generally dictated by the size of the starter and other components used as well as the number and type of loads to be serviced. Examination of manufacturers' literature on individual MCC components, such as molded-case breakers and contactors, shows little variation in principles of operation and materials of construction. Hence, although substantial variations in MCC configuration and features may exist, the constituent components and construction techniques appear to be very similar.[3.11, 3.12, 3.14, 3.15, 3.16, 3.17, 3.18, 3.19, 3.20, 3.25, 3.28, 3.29, 3.32, 3.33, 3.36, 3.37, 3.38, 3.39, 3.40, 3.41, 3.43, 3.45, 3.47]

3.5 Design Requirements: Codes, Standards, and Regulations

3.5.1 Design/Licensing Requirements for Components and Compliance with Applicable Elements of Standard Review Plan, NUREG-0800

3.5.1.1 Design/Licensing Requirements for Motor Control Centers

The basic requirements for development of electric power distribution systems for nuclear power plants are contained in General Design Criteria 17 and 18 of Appendix A to 10 CFR 50. [3.50, 3.51] These criteria provide guidance with respect to design of the application of motor control centers.

The FSARs for various plants provide varying levels of detail regarding MCC licensing commitments. For 480-Vac MCCs, FSARs for the older plants list continuous ratings on the order of 600 amps (with a 25,000-amp rms symmetric bracing for the horizontal bus) or 300 amps (with a 25,000-amp rms symmetric bracing for the vertical bus); MCCBs are indicated to have a symmetric minimum interrupting rating of 25,000 amps rms. FSARs for the newer plants are similar to the older plants with continuous ratings of 600 amps (42,000-amp rms symmetric bracing for the horizontal and vertical buses) and MCCBs with a symmetric minimum interrupting rating of 22,000 amp rms and a symmetric integral current limiter rating of 14,000 amp rms.

In general, although few standards are quoted as licensing commitments related to MCC design, many industry standards are quoted as purchase specification requirements. This ensures that the MCCs are manufactured and tested to current industry standards before they reach the purchaser. The following standards have been used in purchase specifications (Note: other standards may also be applicable):

- ANSI C37.13-1981, "Low-Voltage AC Power Circuit Breaker Used in Enclosures."

- C37.50-1981, "Test Procedures for Low-Voltage AC Power Circuit Breakers Used In Enclosures."
- C57.16-1958, "Requirements, Terminology, and Test Codes for Current-Limiting Reactors."
- C68.1-1978, "American National Standard Techniques for Dielectric Tests."
- C89.2-1974, "Dry-Type Transformers for General Application."
- N45.2-1971, "Quality Assurance Requirements for Nuclear Facilities."
- Z55.1-1967, "Gray Finishes for Industrial Apparatus and Equipment."
- NEMA AB-1-1986, "Molded Case Circuit Breakers."
- NEMA ICS-1-1978, "General Standard for Industrial Control Systems."
- NEMA ICS-1-1985, "General Standard for Industrial Control Systems."
- NEMA ICS-2-1983, "Standards for Industrial Control Devices, Controllers and Assemblies."
- NEMA ICS-4-1983, "Terminal Blocks for Industrial Control Equipment."
- NEMA ICS-6-1983, "Enclosures for Industrial Controls and Systems."
- NEMA ST-20.72-1978, "Dry-Type Transformers General Applications."
- ICEA S-66-524-1980, "Cross-Linked-Thermosetting-Polyethylene-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy."
- NEMA 70-1978, "National Electric Code."
- NFPA 70-1987, "National Electrical Code, Article 430-52."
- UL 44-1983, "Standard for Rubber-Insulated Wires and Cables."
- UL 489-1986, "Molded-Case Circuit Breakers and Circuit Breaker Enclosures."
- UL 508-1984, "Electric Industrial Control Equipment."
- UL 512-1987, "Fuse Holders."
- UL 845-1980, "Electric Motor Control Centers."
- AWS D1.1-1988, "Structural Welding Code, Steel."
- AWS D1.3-1980, "Structural Welding Code, Sheet Steel."
- SSPC PA-1-1982, "Shop, Field, and Maintenance Painting."

One generic issue that applies to safety-related MCCs is the ability of the equipment to function under seismic conditions. Seismic qualification licensing commitments vary with the time of the docketing of the application to the NRC for a construction permit. The earliest plants pre-date explicit seismic qualification requirements for electrical equipment. The applicability of the various versions of Regulatory Guide 1.100[3.52, 3.53, 3.54] and of IEEE Standard 344[3.55, 3.56, 3.57] was determined on a plant-by-plant basis during the licensing process. The "For Comment" version of Regulatory Guide 1.100[3.52] indicates that the guidance of IEEE Standard 344-1975[3.56], as amended by the Regulatory Guide, would be applicable to plants with application for construction permits dated by November 15, 1976. Revision 1 to Regulatory Guide 1.100[3.53] also endorses and amends IEEE Standard 344-1975, but does not state explicit dates of applicability. Revision 2 to Regulatory Guide 1.100[3.54] endorses and amends IEEE Standard 344-1987, and is applicable to plants whose construction permit is issued after June 30, 1988, or whose operating license application is dated after December 30, 1988.

Those plants licensed to Regulatory Guide 1.100 and IEEE Standard 344 had to seismically qualify the equipment by either test or analysis. Most of the MCC designs for more modern plants were subjected to seismic tests. IEEE Standard 344 provides guidance on performing seismic analyses and seismic testing of electrical components. IEEE Standard 344-1975 indicates that when physical testing is performed, five operating basis earthquakes and one safe shutdown earthquake shall be simulated on a specimen. If single axis testing is to be performed, the testing is to be performed for each principal axis. Multi-axis simultaneous testing is also allowed and has become the preference of the industry.

Most MCCs are located in mild environments that do not experience significant changes in temperature, pressure, humidity, and radiation during design basis event (DBE) conditions. As such, MCCs are not usually subject to formal environmental qualification programs by their manufacturers. In certain plants, some MCCs are located in areas that can experience moderately harsh environments in the event of an accident. The environmental qualification of these components is discussed in Section 3.5.2.

IEEE Standard 323-1974 provides general guidance for demonstrating and documenting the adequacy of electrical equipment used in all Class 1E and interface systems. IEEE Standard 649-1980 has been prepared to deal specifically with MCC equipment, using IEEE Standard 323-1974 as the parent document for guidance. IEEE Standard 649-1980[3.58] describes the basic principles, requirements, and methods for qualifying Class 1E MCCs for outside containment applications.

The National Electrical Manufacturer's Association (NEMA) publishes standards that are applicable to the continued use of MCC components in industrial applications. NEMA Standard Publication No. AB-2, "Procedures for Field Inspection and Performance Verification of Molded-Case Circuit Breakers Used in Commercial and Industrial Applications,"[3.59] provides guidance on inspection and preventive maintenance of MCCBs.

[3.60, 3.61]

3.5.1.2 Compliance with Applicable Elements of Standard Review Plan, NUREG-0800

Section 8.1 of NUREG-0800[3.62] provides a Standard Review Plan (SRP) for the NRC review of electric power systems. Although the SRP does not form the licensing basis for the older plants, the SRP was reviewed to identify the issues and concepts related to aging management for motor control centers.

Table 8-1 of the SRP lists the "Acceptance Criteria and Guidelines for Electric Power Systems." Review of this table indicated that the following documents apply to onsite ac power systems:

- General Design Criteria (GDC) 17, "Electrical Power Systems"[3.50]
- GDC 18, "Inspection and Testing of Electric Power Systems"[3.51]
- Regulatory Guide (RG) 1.32, "Criteria for Safety-Related Electric Power Systems for Nuclear Power Plants"[3.63]
- RG 1.118, "Periodic Testing of Electric Power and Protection Systems"[3.64]

Each document was reviewed for specific criteria related to the control of aging of MCC components important to license renewal. No such criteria were located during this review. A summary of the results of each review is included below for completeness.

Document	Content
GDC 17	Provides requirement for electrical system redundance, independence, and testability.
GDC 18	Provides requirements for electrical system design for periodic testing by component or as a whole.
RG 1.32	Describes methods of complying with GDC 17 and GDC 18 with respect to the design, operation, and testing of safety-related electric power systems in all types of nuclear power plants. The criteria, requirements, and recommendation in IEEE Standard 308-1974 are generally acceptable to the NRC staff and provide an adequate basis for compliance.
RG 1.118	Describes a method of complying with the NRC's requirements concerning periodic testing of the protection system and electrical power system for systems important to safety. RG 1.118 also provides supplementary guidance to that included in RG 1.32 regarding periodic testing of electric power systems. The requirements and recommendations contained in IEEE Standard 338-1974 are considered acceptable methods for periodic testing of electrical power and protection systems.

IEEE Standard 308-1980, "IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations,"[3.65] is a general standard that applies to the design criteria and features of Class 1E power systems for a broad grouping of components. Although aging is not addressed in this standard, MCC equipment is included in the scope of the standard as "executive features."

Regulatory Guides offer guidance and interpretation relating to federal law as set forth in 10 CFR 50 and as applied to the design and operation of nuclear facilities. Two Regulatory Guides discuss topics applicable to MCCs and their components. Neither of these Regulatory Guides deals specifically with aging.

Regulatory Guide 1.63, "Electrical Penetration Assemblies in Containment Structures for Nuclear Power Plants,"[3.66] endorses IEEE Standard 317-1983, "IEEE Standard for Electrical Penetration Assemblies in Containment Structures for Nuclear Power Generating Stations,"[3.67] which sets forth requirements for the design, construction, testing, qualification, and installation of electric penetration assemblies in containment structures of nuclear power plants. The regulatory position is based on limiting maximum short circuit flow through containment penetrations to a representative value of the operating time of an MCCB.

Regulatory Guide 1.106, "Thermal Overload Protection for Electric Motors on Motor-Operated Valves,"[3.68] deals with the setting of thermal overloads that are integral with the motor starter for electric motors on motor-operated valves. The regulatory position describes methods of ensuring adequate overload protection and continuity in applications that operate intermittently.

3.5.2 Qualification Limits for Components Exposed to Abnormal Environments

Most MCCs are located in mild environments, areas that experience no significant change in environment as a result of an accident in the plant. However, in some plants, some MCCs may be exposed to secondary effects of a loss-of-coolant accident (LOCA) or high-energy-line break (HELB) outside containment. These conditions exist because MCCs are frequently distributed throughout a power plant and may be located in spaces subject to the effects of HELBs or containing piping with circulating radioactive liquids. These units may be subjected to radiation doses of a few megarads and high-temperature (70° to 82°C [160° to 180°F]), high-humidity conditions as a result of an accident. In most cases, plants having MCCs in harsh environment areas are older plants. The need to qualify the MCCs was frequently identified after the plant was placed in service. Accordingly, generic manufacturers' environmental qualification programs rarely exist for MCCs, and plant-specific tests and analyses were performed. In some cases, these qualification programs may have defined specific replacement schedules for components with organic materials. In other cases, the qualification test may have been purely for accident conditions, and no additional normal maintenance requirements may have been imposed. For plants with MCCs in potentially harsh environment areas, the specific qualification documentation will have to be considered to determine any additional requirements for managing aging during the current and license renewal periods driven by environmental qualification considerations (e.g., parts replacement schedules).

3.6 Operating and Service History

A review of U.S. Nuclear Regulatory Commission Information Notices, Circulars, and Bulletins was conducted to determine the industry-wide operating experience with MCC components. Each applicable Notice, Circular, and Bulletin is discussed in Section 3.6.1 by component. Those Notices, Circulars, and Bulletins that apply to MCCs but were not considered applicable to this report are listed in Appendix B with a justification for elimination.[3.69, 3.70, 3.71, 3.72, 3.73, 3.74, 3.75, 3.76, 3.77, 3.78, 3.79, 3.80, 3.81, 3.82, 3.83, 3.84, 3.85, 3.86] A summary of the operating experience with MCCs is given in Table 3-1. This table is based on a key word search and engineering review of content. It begins with the most significant components and ends with the least significant ones.

Table 3-1. Summary of Operating Experience from Information Notices, Circulars, and Bulletins up to March 1, 1993

Component	Source	Failure	Cause	Recommended Corrective Action
MCC Structural	Circular 77-03	Fire	High resistance at stab connections leading to overheating and fire	Verify that maintenance procedures contain adequate provisions to ensure that the electrical stab connections are properly aligned and full engagement exists between connector stabs and associated bus bars; ensure that bus insulation and supports have sufficient flame retardant ratings
MCCBs	Notice 89-21	Degradation of electrical system; premature tripping	Altered time-current characteristic curves	Breakers should be analyzed for their performance characteristics upon installation
	Notice 92-03	Failure of remote trip functions; premature tripping	Variations in tolerances in accessory trip device mounting, adjustment of ambient bimetal and high temperatures in MCCB	Inspection for the presence of undervoltage releases or shunt trip devices in GE F-frame MCCBs; correction of condition
Magnetic Contactor/ Starter	Notice 91-45	Malfunction of dc coil or sticking of device	Epoxy compound turns semi-fluid because of heat from energization	Manufacturer updated processes and procedures to check for fluid epoxy; inspect normally energized devices; replace devices as necessary
	Notice 92-43	Fracture of armature carrier	Phenolic armature carrier shrinks over time, resulting in inadequate clearances	Inspection and replacement
Thermal Overloads	None			
Misc. Relays	Bulletin 76-05	Open circuit/ excessive opening times	Overheating of coils; insulation breakdown; melting of coil solder	Inspect for defective coil style (Westinghouse BFD) and replacement with newer version
	Bulletin 78-06	Defective coil	Loss of arc gap caused by continuous energization of relay coil	Determine those Cutler-Hammer Type M relays with a dc coil and whether they are used in a continuously energized mode

Table 3-1. Summary of Operating Experience from Information Notices, Circulars, and Bulletins up to March 1, 1993 (continued)

Component	Source	Failure	Cause	Recommended Corrective Action
Misc. Relays (continued)	Circular 79-20	Failure of coil to drop out	Notching caused by rod vibration (coil hum)	Verify armature operating rods of GTE Sylvania PM relays are not notched and are operating freely
	Bulletin 79-25	Relays stuck in energized position with coils de-energized	Epoxy compound fluid binding the armature; heat of energization	Westinghouse recommended a testing method for identifying relays with insufficient over-travel and recommended replacement as necessary
	Notice 82-02	Coil burning and failure	High ambient temperature conditions; inductive voltage spikes upon de-energization of the relay	Westinghouse provided test methods for verification of operability of normally deenergized and energized relay applications
	Notice 82-04	Pneumatic timing diaphragm losing fluid	Exposure to high temperatures causes leakage which affects time delay setting	Return to manufacturer (Agastat) for inspection/possible replacement
	Notice 82-13	Cracking and melting of spool	Heat causes surface cracking and melting of Nylon and Lexan spools	Replace spool with GE Century-Series Tefzel spool
	Bulletin 84-02 and Notice 84-20	Relay failure	Deterioration of coil insulation; melted insulation deposits on armature; binding	Replace GE type HFA relays containing Lexan coil spool wire.
	Notice 88-88	Drag on solenoid armature	Degradation of the coil potting compound	Replacement of Westinghouse ARD recommended
	Notice 91-45	Malfunction of dc coil or sticking of device	Epoxy compound turns semi-fluid because of heat from energization	Westinghouse updated processes and procedures to check for fluid epoxy; inspect normally energized devices; replace devices as necessary
	Notice 92-05	Insulation degradation	Tape used in coil moves allowing short circuit of coil	Identification and replacement of affected coils (Asea Brown Boveri)
Control Transformers	None			
Terminal Blocks	Notice 80-08	Cracking in sliding link	U-shaped sliding link cracks at threaded screwhole resulting in poor electrical connections	Inspection/replacement of defective components

Table 3-1. Summary of Operating Experience from Information Notices, Circulars, and Bulletins up to March 1, 1993 (continued)

Component	Source	Failure	Cause	Recommended Corrective Action
Terminal Blocks (continued)	Notice 82-03	Insulation deterioration	Potential failure during accident conditions	Ensure installation, cleanliness, and on-going maintenance
Wires	Notice 91-20	Insulation degradation of wiring	Moisture, corrosion, electrochemical reaction	Wire was required to be identified and replaced
Fuses/Fuse Holders	Notice 87-62	Varying types of fuse element failures	Four different types of failure, including broken solder joints, wire element elongation, and ohmic heating of eutectic solder	Various, depending on failure type
Switches	None			

A review of MCC failure data from the NPRDS and NRC LERs was also conducted. MCC component failures were analyzed in an attempt to identify significant failure mechanisms and their likelihood of occurrence. These analyses are discussed in Sections 3.6.2 and 3.6.3.

A search of related industry studies was also performed to identify any additional documentation related to industry-wide operating experience with MCCs. The summary of those studies is presented in Section 3.6.4.

Conclusions concerning the overall historical performance of MCCs as represented by the sources listed above are presented in Section 3.6.5.

3.6.1 Description of Industry-Wide Operating Experience with Components

Because of the great diversity of MCC/component manufacturers and equipment configurations, a comprehensive list of specific components used in nuclear plant MCCs could not be prepared. Accordingly, many of the NRC Circulars, Bulletins, and Notices reviewed were included in the following discussion based on their generic relevance as opposed to applicability to a specific piece of equipment. Some of these documents may, therefore, not be directly pertinent to specific manufacturers' equipment installed in MCCs. However, the discussions are illustrative of the types of degradation and failures experienced in the various *classes* of MCC components (i.e., molded-case breakers, relays, wiring, etc.).

3.6.1.1 Motor Control Center Structural Components (Including Metal Housing, Bus Structure, Terminals, and Disconnects)

IE Circular 77-03, "Fire Inside a Motor Control Center,"[3.87] discusses a fire inside an ITE Imperial Series 5600 MCC caused by high resistance connection between the vertical bus and the stab connector assembly of a combination breaker/starter unit. A similar fire had occurred six months earlier at a different nuclear facility for the same reason. The high resistance connection caused localized heating of the stab and ignited a vertical insulation backwall made of fiberglass polyester. The fire essentially destroyed the entire MCC. ITE issued a technical instruction letter to help preclude further occurrences. With regard to removing a combination starter, ITE indicated that plug-in capabilities were incorporated in the design for ease of component replacement and maintenance; however, deformation of the power stabs could occur if units were not protected against mechanical damage. ITE also suggested, because of the importance of loads associated with Class 1E equipment, that stabs be visually inspected periodically.

3.6.1.2 Molded-Case Circuit Breakers

NRC Information Notice 89-21, "Changes in Performance Characteristics of Molded-Case Circuit Breakers,"[3.88] discusses the frequent alteration by MCCB manufacturers of the time-current characteristic curves pertaining to a particular style or type of breaker without changing the part number of the breaker or notifying the customer of the changes. Changes ranged from minor alterations to the thermal portions of the curve to major alterations to the magnetic instantaneous trip portion of the curves.

If not analyzed for performance characteristics, these breakers potentially could, when installed, degrade the electrical protection system and/or cause premature tripping upon the energizing of vital safety-related systems. The notice stated that many perceived failures of circuit breakers detected during pre-installation or routine testing may be the result of unknown changes in time-current characteristic curves.

The following suggestions were recommended to ensure that the breakers purchased conform to a particular curve: (1) referencing of a specific curve (including the applicable revision number) as part of the purchase requirements or (2) analysis of the new curve for its effect on the overall system if the breaker was no longer manufactured to meet the specifications of that specific curve.

NRC Information Notice 92-03, "Remote Trip Function Failures in General Electric F-frame Molded-Case Circuit Breakers,"[3.89] discusses a problem with General Electric (GE) MCCBs undervoltage releases (UVRs) and shunt trip devices that may prevent these internal accessory remote trip devices from functioning properly under conditions that produce sustained high internal temperature in MCCBs. GE reported that the failures were caused by assembly and operational variations resulting from tolerances in mounting accessory devices in the MCCBs, tolerance in the adjustment of the ambient compensating bimetal, and sustained high temperatures in the MCCBs. The cause of the high internal temperature could be traced to a continuous high current load (greater than 50% of the rating for more than two hours) coupled with a high ambient enclosure temperature or secondary heat source.

3.6.1.3 Magnetic Contactor/Starter

NRC Information Notice 91-45, "Possible Malfunction of Westinghouse ARD, BFD, and NBFD Relays, and A200 DC and DPC 250 Magnetic Contactors,"[3.90] discusses the potential for certain Westinghouse-supplied relays and magnetic contactors to fail because of degradation. Failures were attributed to an epoxy compound becoming semi-fluid when the coils were energized for extended periods of time. The epoxy that encapsulates the relay coil was softened by the heat of energization and flowed into the return spring. The failures are widespread throughout the nuclear industry. The manufacturer recommends inspecting all the relays and magnetic contactors that are normally energized, and testing them for epoxy softening after a period of at least two hours of energization.

NRC Information Notice 92-43, "Defective Molded Phenolic Armature Carriers Found on Elmwood Contactors,"[3.91] discusses fractures found in certain Elmwood and Fasco electrical contactors. Elmwood/Fasco Model Series 2M, 3M, 30D, 30E, and 30F contactors manufactured before April 13, 1992, employ a phenolic armature carrier that may shrink over time such that the design clearance fit between the carrier and the steel armature may be inadequate, ultimately resulting in the fracturing of the carrier. These fractured carriers have resulted in the failure of contactors used in operating plant safety systems, thereby causing safety system malfunction.

3.6.1.4 Thermal Overload Relays

There were no reports of MCC-related thermal overload failure in the Bulletins, Circulars, and Information Notices.

3.6.1.5 Relays

IE Bulletin 76-05, "Relay Failures - Westinghouse BFD Relays,"[3.92] reports defective BFD relays. One relay had an open circuit failure, whereas others exhibited excessive opening times. It was determined that the relay failures were caused by overheating of the relay coils, possibly because of continuous energization. Overheating may result in coil insulation breakdown or melting of the coil solder joints, leading to open circuit failure. Also, the overheating may result in deformation of the nylon coil sleeve in which the plunger travels, and this may adversely affect the relay opening time.

IE Bulletin 78-06, "Defective Cutler-Hammer, Type M Relays with DC Coils,"[3.93] reports the failure of four relays caused by loss of arc gap in the coil clearing contact where continuous coil energization is the normal mode of operation. The loss of arc gap was caused by an abnormal amount of heat-induced shrinkage of molded magnet carriers that are used in subject relays manufactured between 1971 and 1976. The magnet carrier shrinks to a point where the arc gap in the coil clearing pole becomes too small to break the inrush current of the pickup coil winding, causing the coil to overheat and burn out. Coil burning may also result in the relay being stuck in the energized position, preventing it from dropping out when the power is removed from the coil. Only the dc coils are affected because the ac coils do not use the coil clearing contact feature.

IE Circular 79-20, "Failure of GTE Sylvania Relay, Type PM Bulletin 7305, Catalog 5U12-11-AC With a 120-Vac Coil,"[3.94] discusses relay failure caused by notching in the armature operating rod. The notch is caused by coil hum where the rod vibrates against the magnet assembly. Many relay failures can be attributed to this effect. This circular recommends inspection of the armature operating rods for notches.

IE Bulletin 79-25, "Failures of Westinghouse BFD Relays in Safety-Related Systems," [3.95] reports of relays found to be stuck in energized positions with the coil de-energized. The armature was sticking to the armature stop post. The condition was found to be a result of heat generated by normally energized coils, which causes a softening and resultant flow of epoxy adhesive used to attach the magnetic anti-stick disc to the top of the armature stop post, bonding the armature to the stop post. Replacement of the relays was requested.

New NBFD relays were suggested as replacements; however, these relays were determined to exhibit marginal or unsatisfactory armature over-travel. It was recommended that relays be tested for insufficient over-travel and replaced if necessary.

IE Information Notice 82-02, "Westinghouse NBFD Relay Failure in Reactor Protection Systems at Certain Nuclear Power Plants,"[3.96] reveals that at high ambient temperature conditions, relay coils (of BFD and NBFD relays) could burn open and fail because of the inductive voltage spike generated by the de-energization of the relay coil.

IE Information Notice 82-04," Potential Deficiency of Certain Agastat E-7000 Series Time-Delay Relays,"[3.97] documents a potential problem with the pneumatic timing diaphragm bleeding fluid, based on exposure to high temperatures for extended periods. This fluid may affect the diaphragm seal such that the time delay setting of the relay is shortened. The temperature necessary to induce this effect was considered to be above that encountered in most relay applications; however, it is still within that required for qualification under IEEE Standards 323 and 344.

IE Information Notice 82-13, "Failures of GE Type HFA Relays,"[3.98] documents surface cracking and melting in the Lexan or Nylon coil spools in GE type HFA relays. GE Service Advice PSM 152.1 (April 28, 1976) advised all users of this problem and recommended replacement of the spool with the new Century Series Tefzel spools (or replacement of the entire relay with the Century model).

IE Bulletin 84-02, "Failures of General Electric Type HFA Relays in Use in Class 1E Safety Systems,"[3.99] and IE Information Notice 84-20, "Service Life of Relays in Safety-Related Systems,"[3.100] discuss the abnormally high failure rate of normally energized GE type HFA relays. The failures, which resulted in the deterioration of the coil wire insulation, were caused by shorted coil turns, which induced increased coil temperatures. The high coil temperatures caused the insulating material to vaporize and the coil spool to melt. These materials then deposited on cooler surfaces of the relay, causing armature damage and/or contact failure. According to the manufacturer, the ac HFA relays manufactured with standard Class A insulation (Nylon or Lexan coil spools and standard temperature wire) that are continuously energized can fail in approximately 10 to 12 years. Replacement with a new model line that uses a high-temperature coil spool and wire employing vacuum-impregnated insulation is recommended.

IE Information Notice 84-20, "Service Life of Relays in Safety-Related Systems,"[3.101] addresses problems noted with Agastat/Amerace GP series and GTE Sylvania ac relays. With regard to the Agastat relays, casing shrinkage subsequent to relay assembly was noted to cause a reduction in clearances and, in some assemblies, mechanical interference between the moving relay contact arm and the stationary base of the relay casing. A design change that provided additional clearance for the contact arm was instituted in 1977 to address this problem. For the GTE relays, problems with the relay coil were noted; in at least one instance the coil was observed to be smoking. The exact failure mode was not yet determined, but was believed to be high coil resistance leading to overheating.

NRC Information Notice 88-88, "Degradation of Westinghouse ARD Relays,"[3.102] addressed deficiencies in 125-Vdc ARD relays that were found to have increased drag between the solenoid's coil spool and the armature. The increased drag was caused by the deterioration of the coil potting compound. The granules from the deteriorated potting lodged between the solenoid's coil spool and the armature. This compound contains a sand-based material that has since been diagnosed to decompose with age.

NRC Information Notice 91-45, "Possible Malfunction of Westinghouse ARD, BFD, and NBFD Relays, and A200 DC and DPC 250 Magnetic Contactors,"[3.90] discusses the potential for certain Westinghouse-supplied relays and magnetic contactors to fail because of degradation. Failures were attributed to an epoxy compound becoming semi-fluid when the coils were energized for extended periods of time. The epoxy that encapsulates the relay coil had softened because of the heat of energization and flowed into the return spring. The failures are widespread throughout the nuclear industry. The manufacturer recommends inspecting all the relays and magnetic contactors that are normally energized, and testing them for epoxy softening after a period of at least at two hours of energization.

Information Notice 92-05, "Potential Coil Insulation Breakdown in ABB RXMH2 Relays," [3.103] discusses the potential failure of this type of relay caused by a short circuit of the coil at the point where the windings used in subsequent layers of the coil cross. Tape had apparently been used to separate the beginning lead and subsequent windings during manufacturing. This tape had been dislocated and the varnish insulation abraded such that the short circuit could occur. ABB noted that the scope of this failure was limited to relays with that particular coil design (type RXMH2, Models RK223068-EA and RK223069-EA manufactured from March 1989 through September 1990).

3.6.1.6 Control Transformer

There were no reports of MCC-related control transformer failure in the Bulletins, Circulars, and Information Notices.

3.6.1.7 Terminal Blocks

IE Information Notice 80-08, "The States Company Sliding Link Electrical Terminal Block,"[3.104] discusses defects with States sliding-link terminal blocks relating to cracking between the threaded screwhole and the side of the U-shaped link. This crack widens when the screw is tightened, resulting in a poor or intermittent electrical connection. The defective link is impossible to cinch tightly and may be difficult to detect by visual inspection. This defective mechanical connection can ultimately result in an electrical circuit malfunction.

IE Information Notice 82-03, "Environmental Tests of Electrical Terminal Blocks," [3.105] published the results of a test conducted to investigate the deterioration of terminal blocks' insulators under accident conditions. The Notice describes the importance of cleanliness of terminations and terminal blocks in safety-related circuits and discusses those regulations required of licensees for establishing appropriate procedures for the cleanliness and installation integrity of these devices. Licensees are reminded that the plant preventive maintenance program in use at their facilities should ensure that (1) proper operation of all essential components is achieved throughout the life of the plant and that (2) periodic inspection of those terminations and terminal blocks for cleanliness and installation integrity is performed following any maintenance activity affecting them.

3.6.1.8 Control Wiring

NRC Information Notice 91-20, "Electrical Wire Insulation Degradation Caused Failure in a Safety-Related Motor Control Center,"[3.106] discusses the failure of a motor-operated isolation valve to operate on demand during surveillance testing. Failure was attributed to a foreign hardened coating on one of the contactors within the associated MCC. The source of the hardened coating was traced to a green liquescent substance coming out of the dielectric polyvinyl chloride (PVC) wiring used in the MCC. This substance was caused by a combination of an electrochemical reaction, moisture from the environment, interaction between the corrosion products formed on the surface of the copper wire, and the chlorine leaching from the wire's PVC insulation, which may have all been accelerated by the high voltage differential across the control transformer. Other utilities reportedly found evidence of this wire breakdown in their MCCs.

3.6.1.9 Fuses/Fuse Holders

Information Notice 87-62, "Mechanical Failure of Indicating-Type Fuses,"[3.107] describes four separate events of pin indicating-type fuse mechanical failure. In the first case, a Bussmann FNA-type fuse caused a main feedwater isolation valve to close when the fuse element pulled loose from the solder joint inside the fuse. Of the spare fuses in stock, 8% were also noted to have failed mechanically. The second event was also caused by mechanical failure of an FNA-type fuse. The third event was related to the Bussmann MIS-5 type actuating fuse, which uses two very thin wires (one silver wire acting as the fusible link and one nichrome wire acting as the retaining mechanism for the fuse actuator); elongation of the wire(s) over time significantly altered the current-carrying characteristics of the fuse over time. The fourth event described in this Notice relates to Littlefuse FLAS-5 type fuses, which use a fuse wire in parallel with a resistor and eutectic alloy solder; heating of the resistor during overcurrent conditions produces excessive heat and causes the alloy to melt prematurely and the fuse to open accordingly.

3.6.1.10 Switches

There were no reports of MCC-related switch failure in the Bulletins, Circulars, and Information Notices.

3.6.2 Evaluation of NPRDS Data

To substantiate the stressors and aging mechanisms postulated for MCCs, actual plant component failure data were sought. One of the primary sources of this type of failure data is the NPRDS. Failure records contained in NPRDS include such information as the voltage class and manufacturer, type of equipment, date of discovery, cause category, and a brief narrative describing the event. NPRDS data are not focused directly on component aging, as it does not typically address the root cause or mechanism of component degradation. Additionally, not all degradations observed during maintenance activities are identified in the database. Not all plants have provided NPRDS data, and those that have may not have reported for their entire period of operation. As a result of these limitations, the database cannot be readily used to provide probabilistic information about the reliability of a specific population of components with respect to age-related degradation. However, the data can be used to identify those MCC subcomponents that have a high incidence of degradation or failure relative to other subcomponents within the same equipment.

By permission of the INPO, failure and deterioration data contained in the NPRDS database were reviewed as part of this study. More than 3000 reports were generated through the search of the database. Reports pertinent to MCC subcomponent failures were identified; these reports were then individually evaluated to determine their applicability to aging and aging mechanisms. Failure reports deemed to be applicable were then grouped by manufacturer and component; each component failure grouping was then sorted by subcomponent and failure mode (if known). The following subsections summarize the specific observations by manufacturer and component. A summary of the overall findings of the NPRDS review is provided at the end of this section.

As previously discussed, NPRDS data for MCCs were grouped by associated components. No failures of the metal housing or bus structure components were noted; hence, these components are not included in the following analyses. Further discussion of the housing/bus structure is contained in Section 3.4 of this guideline. Hardware used in the assembly of the MCC was generally associated with the component to which it was related (i.e., bolts used to assemble the housing were included with the housing, nuts used on terminal connections were included with the terminal blocks, etc.). Fuses (as distinguished from fuse holders) were not considered in the analyses.

In several cases, the failed subcomponent and/or failure mode was not identified; these reports were tagged as "unidentified." This was especially prevalent in the molded-case breaker and relay categories, as these items are considered replaceable and in-depth failure analysis is rarely conducted. (In the case of MCCBs, the case is sometimes sealed and may not be readily accessible for inspection/analysis.) These reports do, however, provide additional perspective as to the fraction of reports (related to a specific component) that did not contain sufficient information for analysis. In those cases where substantial percentages of the reports cannot be attributed to any subcomponent or failure mode, the overall results may not be representative of the total population. For example, if most of the "unidentified" failures for a given component are, in fact, caused by one or two subcomponents (as opposed to being proportionately distributed among all of the subcomponents), the data (and results) are accordingly skewed. In sum, the accuracy of the conclusions is, to a degree, related to the percentage of "unidentified" reports present for the individual component.

It should also be noted that "normal wear" was cited in numerous reports as the cause for the component/subcomponent failure. In most cases, this term is not descriptive of the actual failure mode; however, these reports were assigned their own failure mode category so as to differentiate them from other failure modes and provide some indication of the fraction of total failures that these reports constitute.

Many of the reports pertinent to this analysis also required a substantial degree of interpretation; incomplete and even contradictory descriptions of the circumstances surrounding the failure were sometimes noted. In cases where the ambiguity could not be resolved with any degree of certainty, the report in question was not used. Because of the uncertainty inherent in some of the data, the relative proportions of various types of failures may differ somewhat from the "actual" values; this potential error was assumed to be evenly distributed (that is, reports erroneously attributed were assumed not to affect one component, subcomponent, or failure mode grouping disproportionately in relation to another).

Two other aspects of component failure were also considered as part of the NPRDS analysis. First, each failure report was examined to determine the method of detection; this provides information on the relative proportions of failures which were identified during maintenance, inspection, testing, and operations. These analyses are presented in each of the applicable sections below. Second, those reports detected during operations were examined to determine which failures impacted the functionality of the associated system and which did not. It should be noted that a substantial percentage of these component failure reports (approximately one-third of all failures detected during operations) did not contain sufficient information to definitively determine the effect of the component failure on connected loads or systems. However, a loss of system/connected load functionality was noted in the majority of those reports (i.e., the remaining two-thirds) where a determination of system/load functionality could be made. Additionally, the relationship between component failures and the functionality of systems important to license renewal (ITLR) could not be determined from the reports since in general, insufficient information regarding the function of each component was provided. Therefore, for the purposes of this study, it was conservatively assumed that *all* component failures noted adversely impacted the functionality of the system which they supported.

Component failure rate as a function of installed age was also considered during the data evaluation. For some of the components such as the metal housing system, the in-service date (which in most reports corresponded to the plant construction or initial criticality date) was likely the actual installation date. However, these components had such a low overall failure rate that no statistically meaningful correlation between age and failure rate could be made. For other components that may have been replaced several times subsequent to plant construction (such as continuously energized relays or MCCBs), the in-service date was deemed unlikely to be the actual installation date of the component. Because of these limitations, no attempt to correlate failure rate with installed age was made for any of the components.

Those NPRDS reports stemming from prior equipment maintenance, modification, or surveillance testing were classified as "maintenance-induced"; failures resulting from maintenance-induced causes were identified in each of the discussions presented below, yet were not included in the component/failure mode analysis. Maintenance-induced events, although not strictly an aging mechanism, do constitute a viable mechanism for MCC component degradation over time. Section 3.6.2.5 of this guideline discusses maintenance-induced events in further detail.

The subsections that follow analyze the NPRDS data in a number of different ways. First, data for all manufacturers and MCC components are examined to determine the relative proportions of subcomponent failures in general (Section 3.6.2.1). Second, data specific to each manufacturer of MCC components are analyzed to determine the relative proportion of component failures by manufacturer (Section 3.6.2.2). Third, data for all manufacturers and components are collectively analyzed for subcomponent failures and failure modes (Section 3.6.2.3). Finally, subcomponent failures and failure modes are examined for components from each manufacturer (Section 3.6.2.4). Collectively, these analyses present a comprehensive characterization of MCC component/subcomponent failures as indicated by the NPRDS database. (Note: Because of the inaccuracies and uncertainties present in the data, all percentage values listed in the following sections are rounded to their nearest whole digit.)

Figures 3-14 through 3-25 are pictorial representations of the analyses described in the preceding paragraph. The "pie-chart" plots show the relative distribution of component failures, subcomponent failures, failure modes, and methods of detection. Histogram plots have been used to show significant combinations of failed subcomponents and failure modes for a given component. In most cases, minimum levels of significance were chosen for the histogram plots (usually 5% of the total number of reports applicable to the component under consideration) to eliminate lesser subcomponent failure modes, yet still identify combinations of significance.

3.6.2.1 MCC Component Failure Analysis (All Manufacturers)

A total of 1097 failure reports were compiled for all manufacturers of MCCs and components. Of these reports, 60 (5%) were considered maintenance induced. Figure 3-14 shows a graphic representation of this data. As evidenced by the figure, circuit breaker failures constituted the highest percentage of failures (36%), followed closely by starters/contactor assemblies (33%). The next most prevalent component to fail was thermal overload relays (13%), followed by miscellaneous relays (9%) and wiring (4%). The remaining categories (control transformers, switches, terminal blocks, and fuse holders) collectively made up approximately 6% of the total.

With respect to method of failure detection, 39% of all failures (all types of components and manufacturers) were detected during operations (see Figure 3-15). The next most significant method of detection was surveillance testing, during which 29% of all failures were found.

Failures detected during in-service inspections, special inspections, and routine observations accounted for 18%, while the remaining 15% of the failures were noted during preventive or corrective maintenance activities. Component-specific analysis for method of detection (for all manufacturers) is shown in Table 3-2.

Table 3-2. Method of Detection for Individual MCC Components (All Manufacturers)

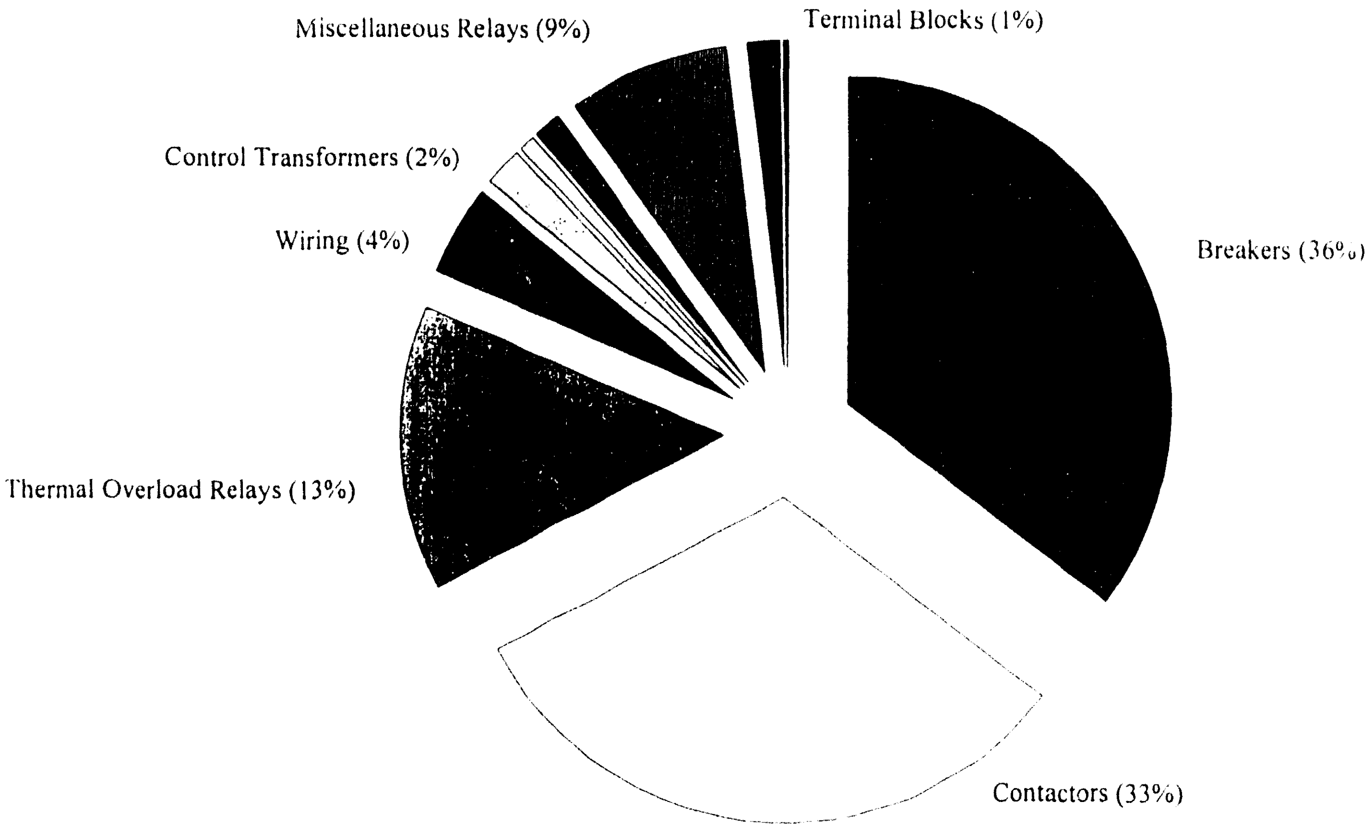
Component	Operations	Surveillance	Maintenance	Inspection
Circuit Breakers (376)	39%	23%	12%	26%
Starter/Contactor (340)	41%	40%	8%	11%
Overload Relay (138)	28%	27%	29%	16%
Misc. Relay (89)	54%	34%	3%	9%
Control Transformer (20)	65%	15%	5%	15%
Wiring (35)	43%	23%	11%	23%
Terminal Blocks (14)	50%	36%	14%	0%
Fuse Holders (16)	44%	0%	12%	44%
Switches (7)	14%	43%	29%	14%
Bus/Structure (2)	50%	0%	0%	50%

Note: Numbers in parentheses indicate the total number of reports applicable to that component.

When only those failures detected during operations are considered, 35% of these failures were related to circuit breakers, 33% were related to starters/contactors, 10% to overload relays, 8% to miscellaneous relays, and 5% to wiring. This result very closely parallels that obtained when all methods of detection are included, indicating little relationship between detection during operation and the rate of failure for a given component.

3.6.2.2 MCC Component Failure Analysis (Manufacturer Specific)

Data for five major MCC/component manufacturers (General Electric, Westinghouse, Gould/ITE, Cutler-Hammer, and Klockner-Moeller) are presented in the following sections. Although NPRDS data for several additional manufacturers were present (including Heinemann, Square D, GTE Sylvania, Agastat/Amerace, Allen-Bradley, Struthers-Dunn, Cooper, Furnas, Arrow, Power Conversion, Siemens-Allis, Zurn, and Nelson/Sola), the data were numerically insufficient to permit any inferences regarding component reliability. Additionally, not all manufacturers produce each of the components under consideration in these analyses. As a result, only those manufacturers with both an adequate diversity of products and adequate number of supporting failure records were chosen for the following analyses.



Based on 1037 Reports

(Note: Fuse Holders, MCC Structural Components, and Switches each <1% of total)

Figure 3-14. MCC Component Failures (All Manufacturers)

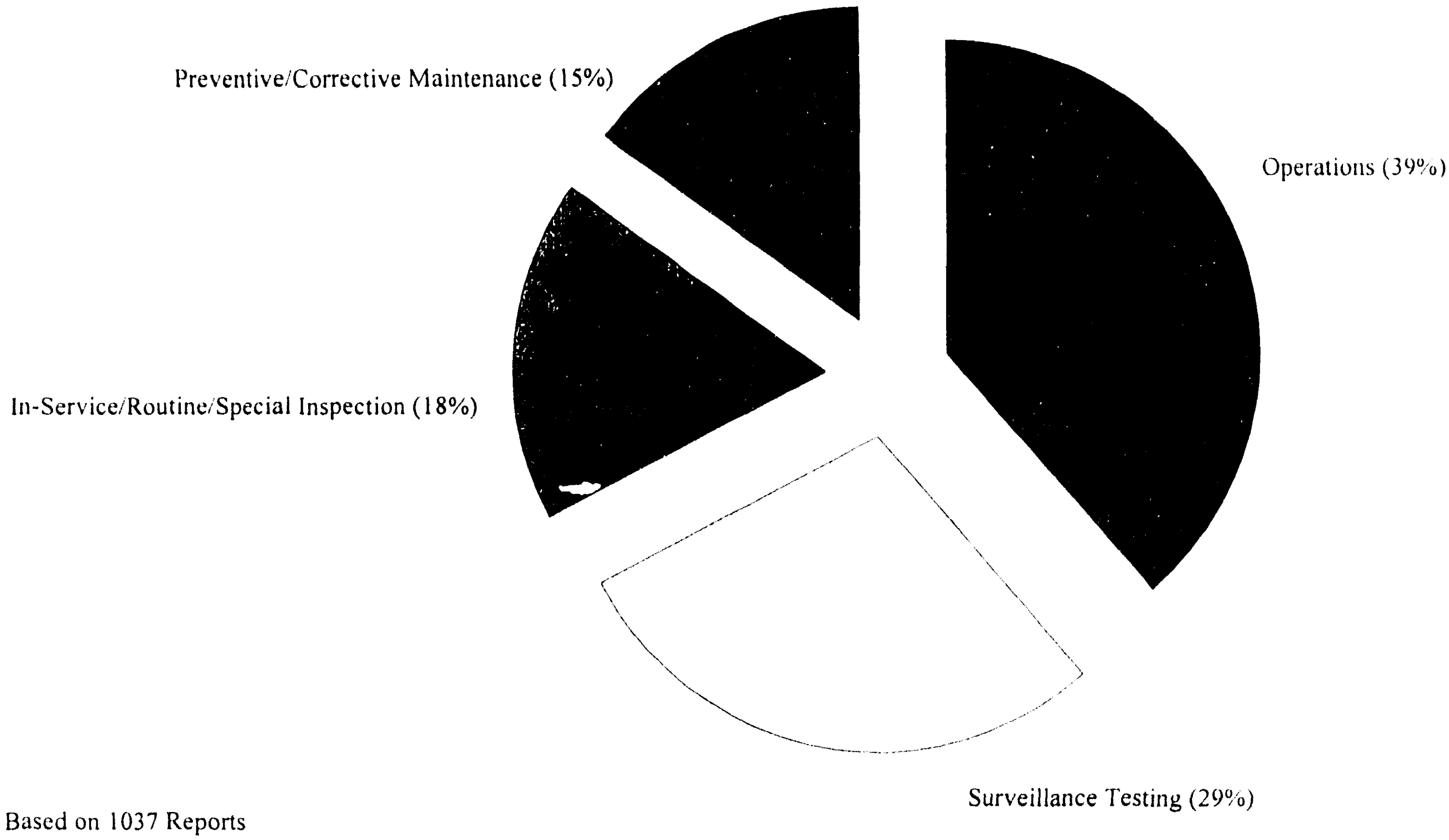


Figure 3-15. Method of Detection — MCC Component Failures (All Manufacturers)

3.6.2.2.1 General Electric

A total of 361 failure reports were generated for General Electric MCCs and their components. Nine of these reports (3%) were considered to be maintenance-induced events. As shown in Figure 3-16, starters/contactors made up the largest percentage of the remaining failure reports (42%). Reports associated with MCC breakers were next most numerous (31%), followed by thermal overload relays (14%) and miscellaneous relays (5%). The remaining component categories collectively amounted to less than 10% of the failures reported.

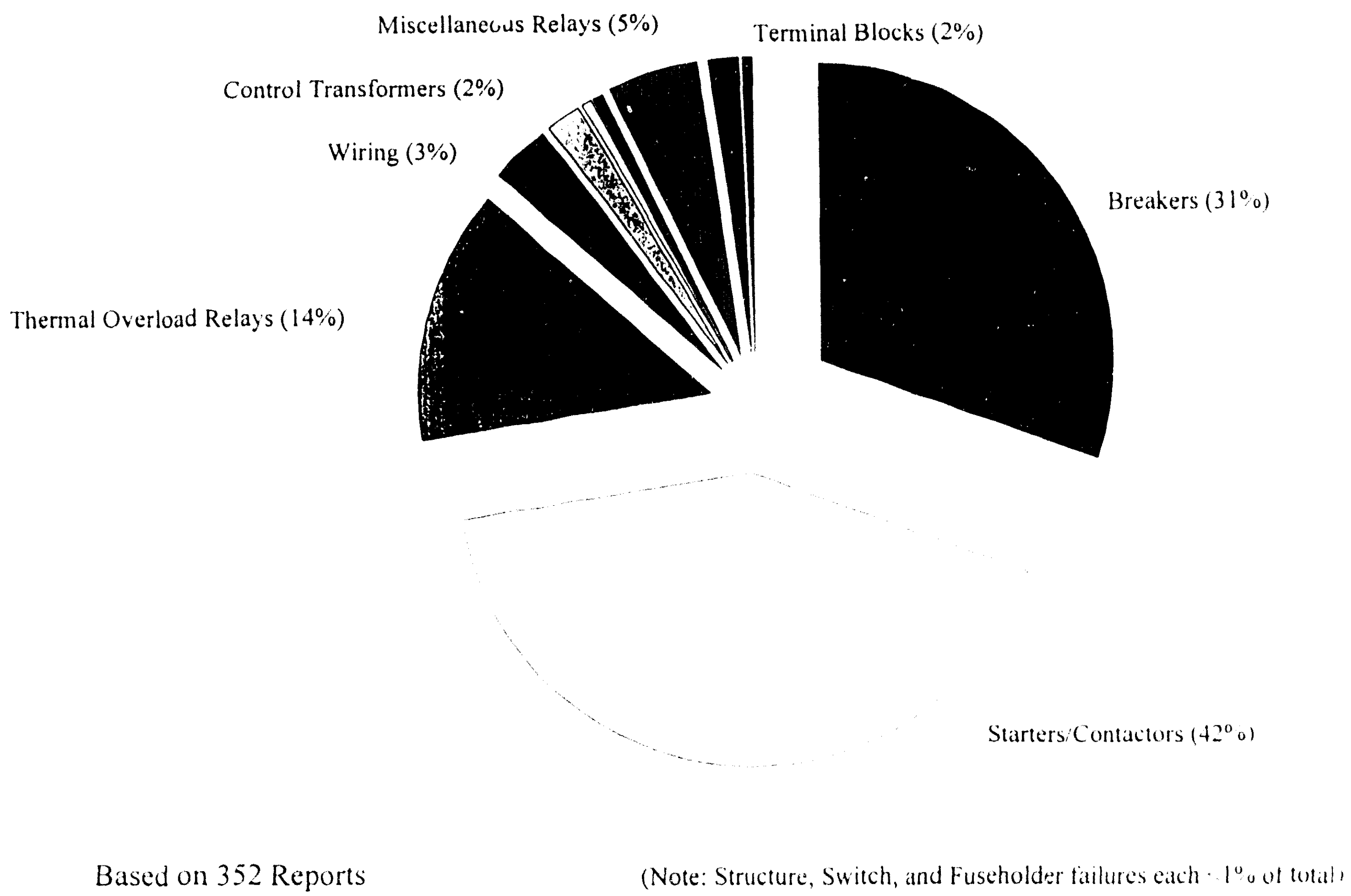


Figure 3-16. General Electric MCC Component Failures.

General Electric component failures were most often detected during operations (40% of all GE component reports), followed by those detected during surveillance testing (31%) and maintenance (20%). Component-specific breakdowns of detection method are shown in Table 3-3.

Table 3-3. Method of Detection for Individual General Electric MCC Components

Component	Operations	Surveillance	Maintenance	Inspection
Circuit Breakers (108)	41%	24%	20%	15%
Starter/Contactor (149)	41%	42%	11%	6%
Overload Relay (49)	17%	25%	56%	2%
Misc. Relay (18)	72%	16%	6%	6%
Control Transformer (6)	66%	17%	17%	0%
Wiring (11)	45%	27%	9%	18%
Terminal Blocks (6)	50%	33%	17%	0%
Fuse Holders (2)	100%	0%	0%	0%
Switches (2)	50%	50%	0%	0%
Bus/Structure (1)	100%	0%	0%	0%

Note: Numbers in parentheses indicate the total number of reports applicable to that component

3.6.2.2.2 Westinghouse

A total of 344 failure reports were gathered for Westinghouse equipment; 30 of these reports (9%) were maintenance-induced. Figure 3-17 depicts the relative distribution of component failures for the remaining 314 reports; this distribution appears to be similar to that for all manufacturers described in Section 3.6.2.1 above (Figure 3-14) with the exception that thermal overload relays make up a somewhat larger percentage (19% vs. 14%) of the reports.

Westinghouse component failures were most often detected during operations (43% of all Westinghouse component reports), followed by those detected during surveillance testing (24%), inspection activities (22%), and maintenance (11%). The results of the component-specific evaluation of method of detection is in Table 3-4.

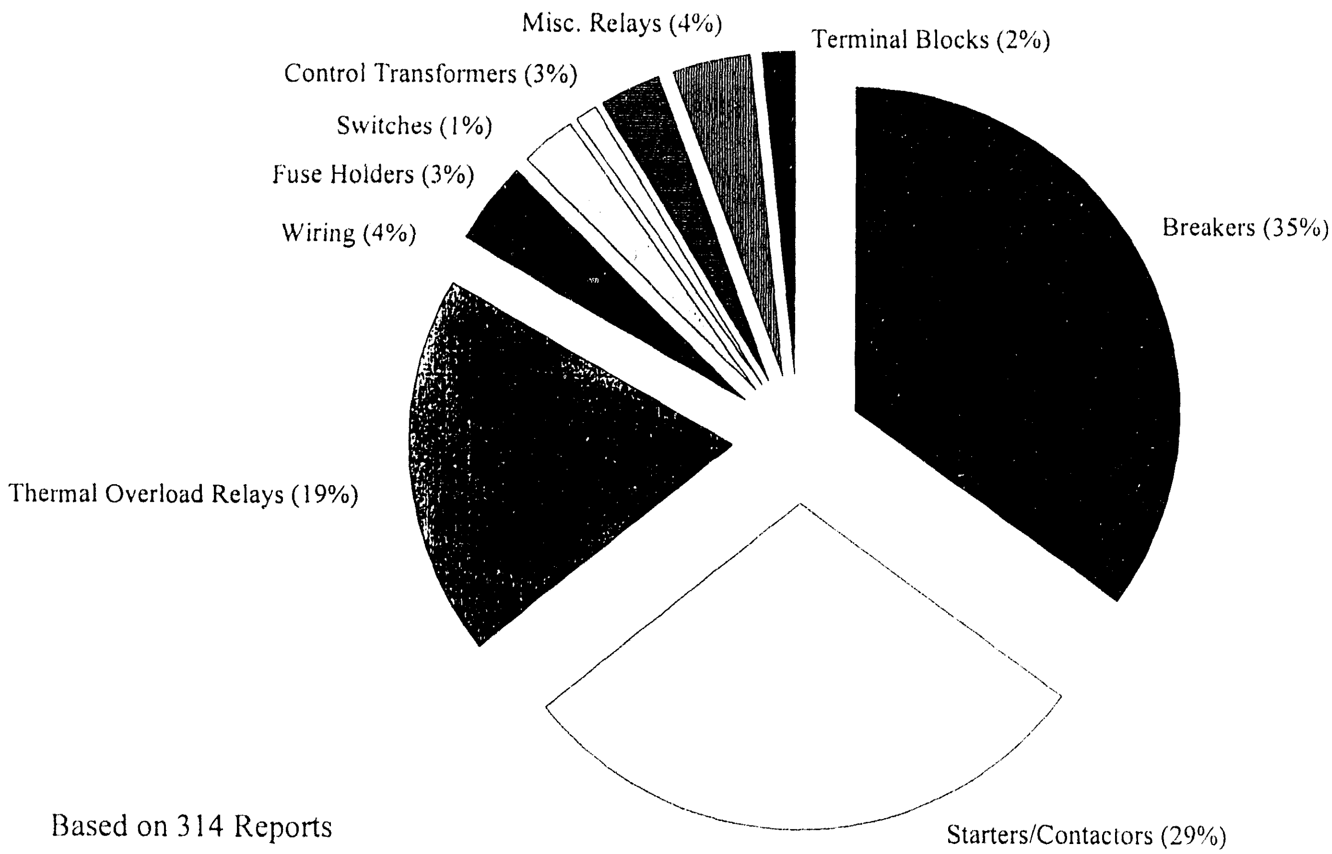


Figure 3-17. Westinghouse MCC Component Failures.

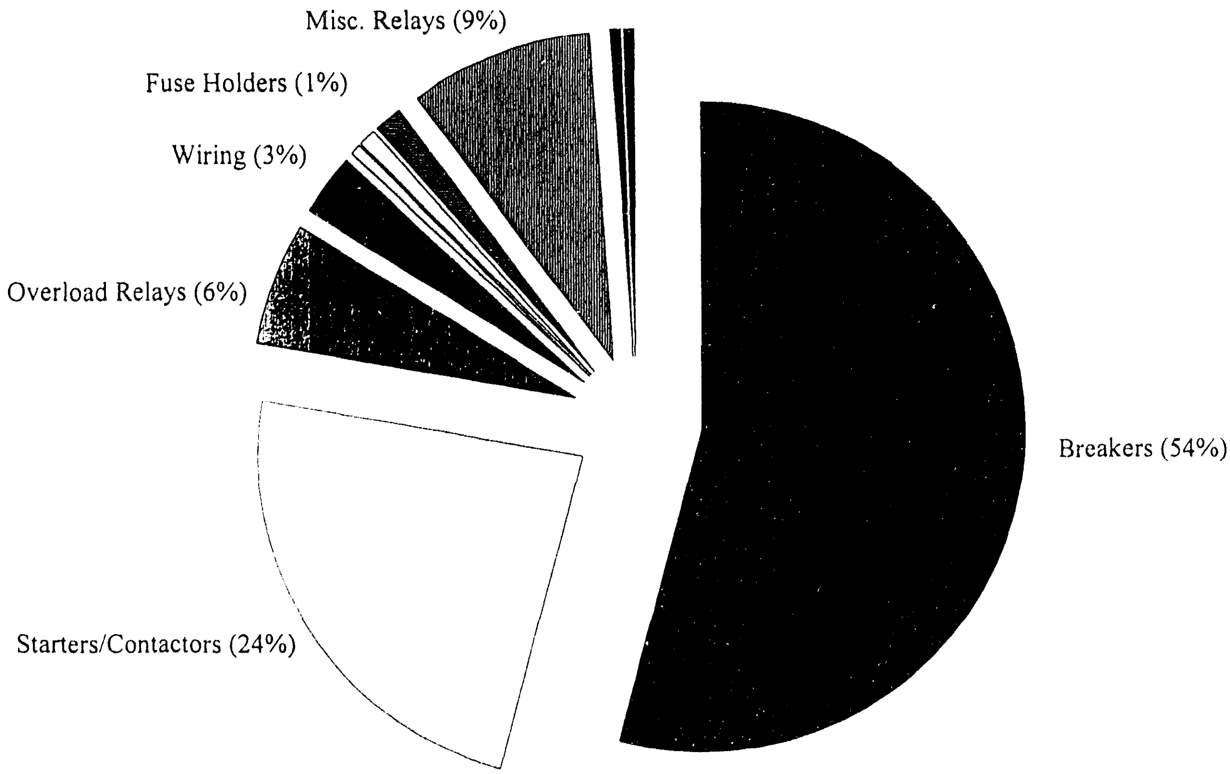
Table 3-4. Method of Detection for Individual Westinghouse MCC Components

Component	Operations	Surveillance	Maintenance	Inspection
Circuit Breakers (110)	51%	18%	12%	19%
Starter/Contactor (91)	42%	31%	9%	18%
Overload Relay (60)	32%	31%	15%	22%
Misc. Relay (10)	50%	30%	0%	20%
Control Transformer (9)	44%	23%	0%	33%
Wiring (18)	33%	17%	11%	39%
Terminal Blocks (5)	80%	20%	0%	0%
Fuse Holders (8)	38%	0%	12%	50%
Switches (3)	0%	0%	67%	33%
Bus/Structure (0)	0%	0%	0%	0%

Note: Numbers in parentheses indicate the total number of reports applicable to that component

3.6.2.2.3 Gould/ITE

A total of 239 reports related to Gould/ITE MCC components were identified. Of these reports, 13 (6%) were maintenance-induced. Breaker failures constituted more than half (54%) of the remaining failures noted (see Figure 3-18); this is a significantly larger fraction than for any other component manufacturer. In addition, the percentages of overload relay and starter/contactor failures were somewhat lower than those noted for all manufacturers (see Figure 3-14).



(Note: Control Transformers, Terminal Blocks, Structure, and Switches each <1% of total)

Based on 226 Reports

Figure 3-18. Gould/ITE MCC Component Failures.

The largest percentage of Gould/ITE component failures were detected during operations (34%), followed by surveillance testing (31%), inspection activities (29%), and maintenance (6%). For each individual component, the results shown in Table 3-5 were obtained.

Table 3-5. Method of Detection for Individual Gould/ITE MCC Components

Component	Operations	Surveillance	Maintenance	Inspection
Circuit Breakers (122)	27%	25%	5%4	3%
Starter/Contactor (53)	38%	50%	3%	9%
Overload Relay (12)	42%	25%	8%	25%
Misc. Relay (19)	53%	36%	0%	11%
Control Transformer (1)	100%	0%	0%	0%
Wiring (11)	64%	9%	9%	18%
Terminal Blocks (3)	33%	67%	0%	0%
Fuse Holders (2)	50%	0%	50%	0%
Switches (2)	0%	100%	0%	0%
Bus/Structure (1)	0%	0%	0%	100%

Note: Numbers in parentheses indicate the total number of reports applicable to that component

3.6.2.2.4 Cutler-Hammer

A total of 44 reports were applicable to Cutler-Hammer MCC equipment; 2 of these reports (5%) were maintenance-induced. Figure 3-19 shows the relative proportions of failures for Cutler-Hammer MCC components; starters/contactors were responsible for the largest percentage (52%) of the failures reported. Breakers, on the other hand, were responsible for only 10% of the reports noted. This result may be due, in part, to the potentially high statistical variance in the data (i.e., with a low total number of reports, each additional report has a disproportionate effect on the distribution).

Cutler-Hammer component failures were most often detected during operations (44% of all reports), followed by surveillance testing (35%), inspection activities (12%), and maintenance (9%). Because of the low total number of reports applicable to Cutler-Hammer equipment, no component-specific analysis of method of detection was conducted.

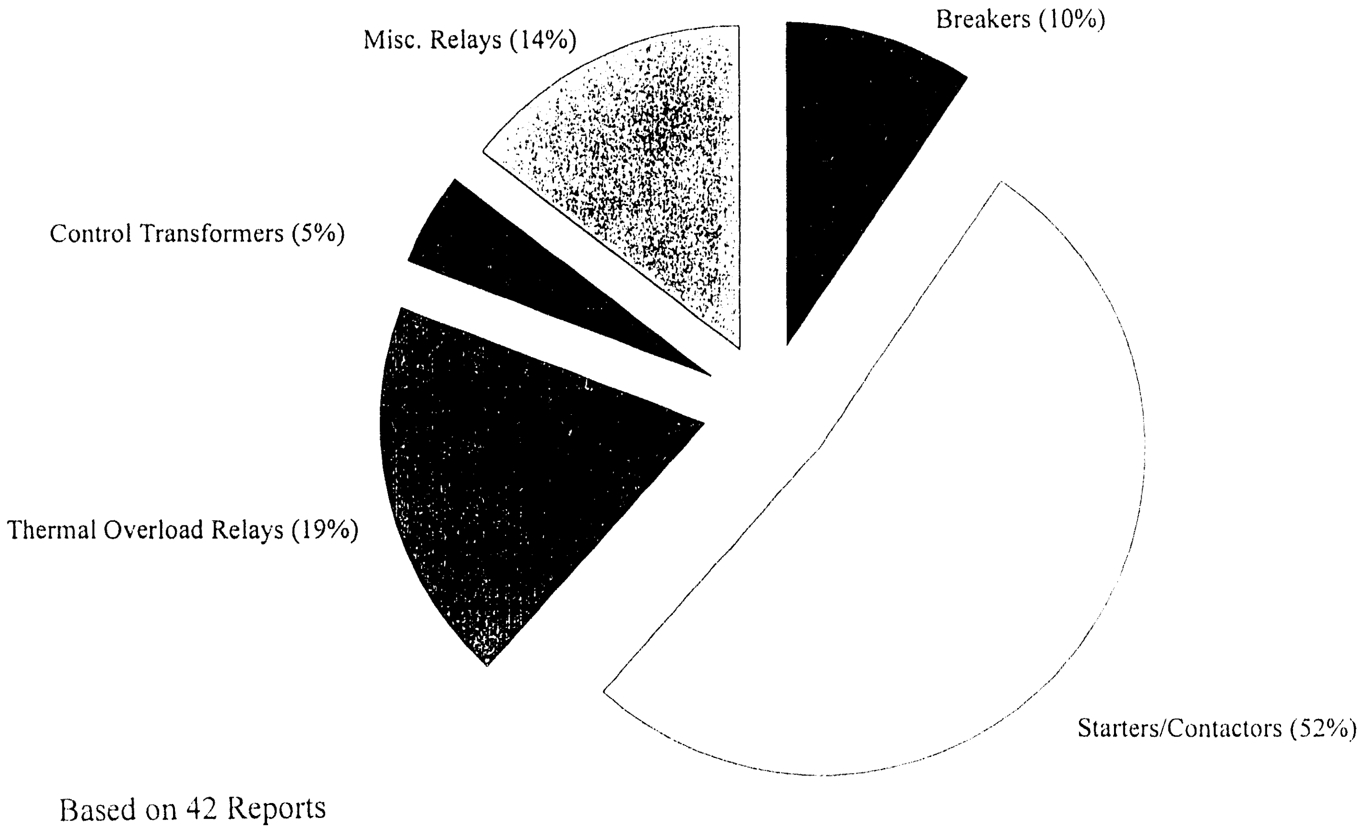
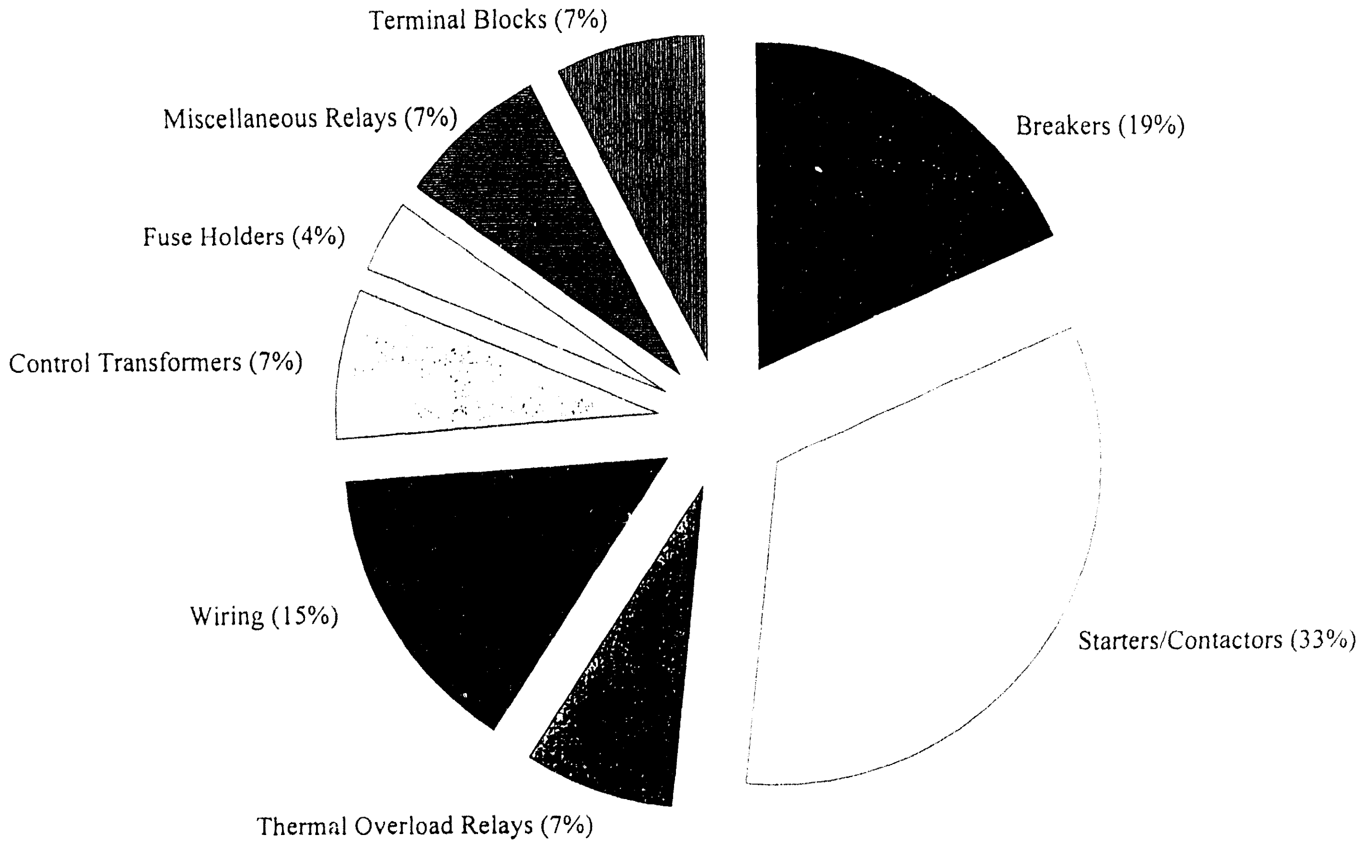


Figure 3-19. Cutler-Hammer MCC Component Failures.

3.6.2.2.5 Klockner-Moeller

A total of 28 reports were cited for Klockner-Moeller equipment. Only one of these reports was considered maintenance-induced. As shown in Figure 3-20, starters/contactors accounted for the highest fraction of failures noted (33%); breakers were responsible for 19%, and wiring for 15% of the total. The remaining components each accounted for nearly equal fractions (7%). The largest percentage of Klockner-Moeller component failures were detected during surveillance testing (43%), followed by inspection activities (29%), operations (25%), and maintenance (3%). However, because of the low number of reports applicable to this equipment, these results may not be representative of the total population. No component-specific analysis of method of detection was conducted for Klockner-Moeller equipment.



Based on 27 Reports

Figure 3-20. Klockner-Moeller MCC Component Failures.

3.6.2.3 Subcomponent Failure Analysis (All Manufacturers)

To accurately represent the historical aging and degradation of MCC equipment, each of the MCC components described above was broken down into its constituent subcomponents (where applicable); each NPRDS report examined was attributed to the appropriate subcomponent when identified. In addition to distinguishing these subcomponents, potential failure modes for each of these subcomponents were also listed. This characterization process was ultimately used to identify those combinations of failed subcomponents/failure modes that were significant (because of their high frequency of occurrence relative to other subcomponent/failure mode combinations).

The following paragraphs discuss the analysis of subcomponent failures (all manufacturers) for each of five component categories (breakers, starters/contactors, miscellaneous relays, wiring, and overload relays). These five categories were chosen based on the numerical sufficiency of their supporting data; the remaining component groups (fuse holders, control transformers, switches, and terminal blocks) had an inadequate number of reports from which to draw inferences regarding their relative reliability.

3.6.2.3.1 Breakers

A total of 389 reports were noted for MCC breaker failures. Of these reports, 3% (13) were related to prior maintenance or testing of the equipment. The largest percentage of the identified failures was attributable to breaker operating handles/linkages (18%). This was followed by failures of the internal breaker operating mechanism (12%), the overcurrent trip device (12%), and the trip mechanism (6%). A total of 32% of the failures were attributable to unidentified subcomponents. However, a large fraction of these reports may be considered to result from subcomponents internal to the breaker itself, because many of these reports cite (1) replacement of the breaker as a unit as the ultimate corrective action, (2) the lack of any failure analysis performed because of the breaker being sealed and/or expendable, and (3) identification of the "breaker" as the failed component. Hence, the other subcomponent categories external to the breaker (operating handle, external wiring connections, and hardware) may be considered to be somewhat less significant when the reports with unidentified subcomponents are included in the evaluation.

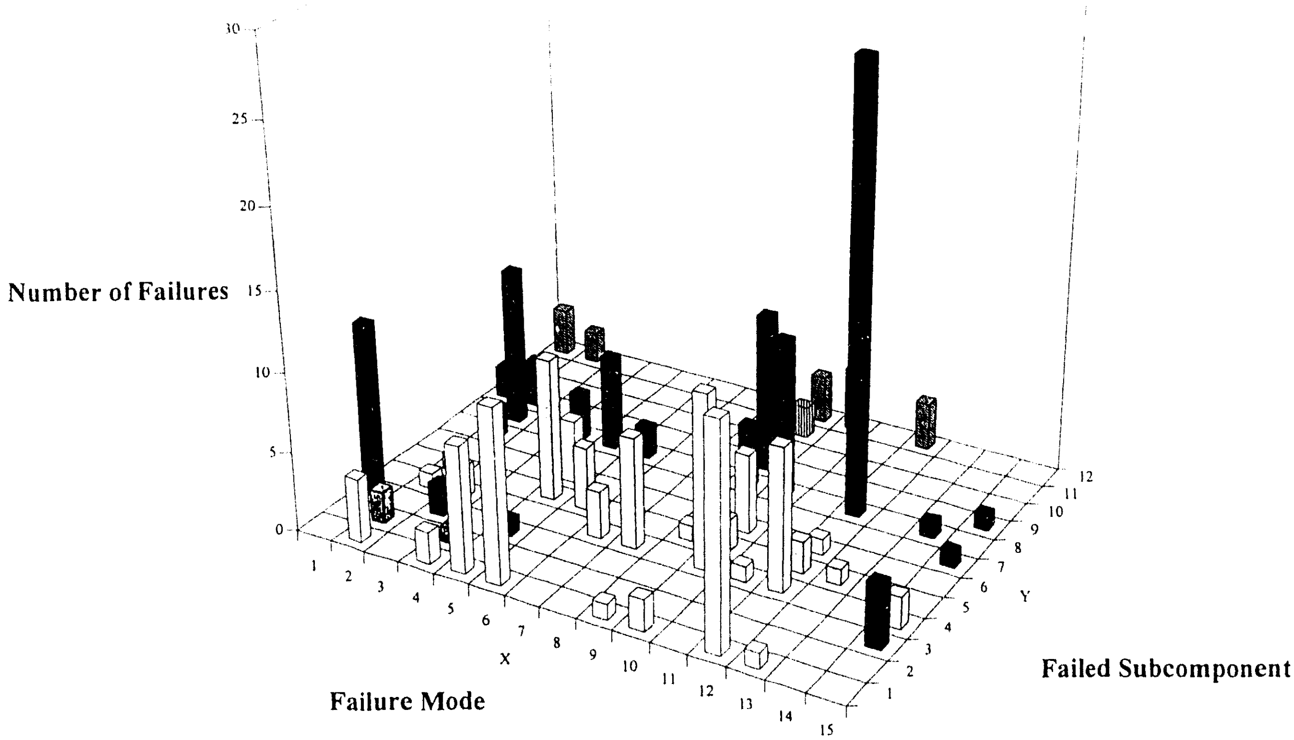
The most predominant failure modes associated with MCC breakers (all manufacturers) was normal wear/aging (27% of all breaker reports). Unidentified failure modes constituted 23% of all breaker reports, followed by loss of adjustment/calibration (10%), binding/sticking (8%), and broken or deformed parts (7%).

A total of 17% of all reports had both an unidentified failed subcomponent and failure mode. The most significant combinations of identified subcomponent/failure mode (see Figure 3-21) include normal wear of the operating handle/linkage parts (12% of the reports with identified subcomponents and failure modes), normal wear of the breaker internal operating mechanism (6%), inadequate lubrication of the operating mechanism (5%), loss of calibration of the overcurrent trip device (5%), contamination, pitting, or corrosion of the main contact surfaces (5%), and loose electrical connections (4%).

3.6.2.3.2 Starters/Contactors

A total of 345 reports were applicable to starters/contactors of all manufacturers. Of these reports, less than 2% (5) were the result of maintenance or testing activities. Of the remaining reports, 36% were associated with auxiliary contact assemblies; 21% were because of the main contactor mechanism, 17% were related to the contactor coil(s), and 9% for each of the main contact surfaces and mechanical interlocks. (Note: Mechanical interlocks may not be used in all applications; hence, the failure rate of these devices may actually be higher than 9%.) A total of 4% of the reports failed to identify the problematic subcomponent.

The predominant failure modes associated with starters/contactors were also analyzed. Of all failures, 25% were the result of binding or sticking, 14% were caused by contaminated, pitted, or corroded parts, and 12% were caused by normal wear/aging. A total of 11% of the reports had unidentified failure modes.



Based on 231Reports

Number	Failure Mode (X)	Failed Subcomponent (Y)
1	Dirty/pitted/corroded	Operating mechanism
2	Deformed/broken	Latches
3	Heat damage	Contact surfaces
4	Cyclic fatigue	Trip device
5	Binding/sticking	Trip mechanism
6	Inadequate lubrication	Aux. breaker contacts
7	Open circuit	Casing
8	Fault	Handle/interlock
9	Loose	Electrical connections
10	Out of adjustment	Terminations
11	Out of calibration	Hardware
12	Normal wear	Other
13	Cracked	
14	High electrical resistance	
15	Other	

Figure 3-21. Significant MCCB Subcomponent/Failure Mode Combinations (All Manufacturers).

Less than 3% of all reports had both an unidentified failed subcomponent and failure mode. The most significant combinations of identified subcomponent and failure mode (Figure 3-22) include binding and/or sticking of the auxiliary contacts (14% of all reports with identified failed subcomponent and failure mode), binding and/or sticking of the main contactor mechanism (9%), and contamination, pitting, or corrosion of both the main contact surfaces (7%) and auxiliary contacts (6%).

3.6.2.3.3 Thermal Overload Relays

A total of 155 reports were noted for MCC thermal overload relay failures. Of these reports, 17 (11%) were related to prior maintenance or testing of the equipment. Of the remaining reports, the largest percentage of identified failures was attributable to the overload heater elements (17%). A total of 49% of the reports were the result of failures of unidentified subcomponents. The remaining portion of the reports were distributed across other overload relay subcomponents in lesser percentages (6% related to the contact mechanism, 3% each because of mounting hardware, electrical connections, and support blocks, etc.).

With respect to failure modes, the most common reason cited for thermal overload relay failure was normal wear/aging (36%). Unidentified failure modes constituted 28% of all overload reports, followed by loss of adjustment/calibration (5%), heat damage (5%), loose subcomponents (5%), and broken or deformed parts (5%).

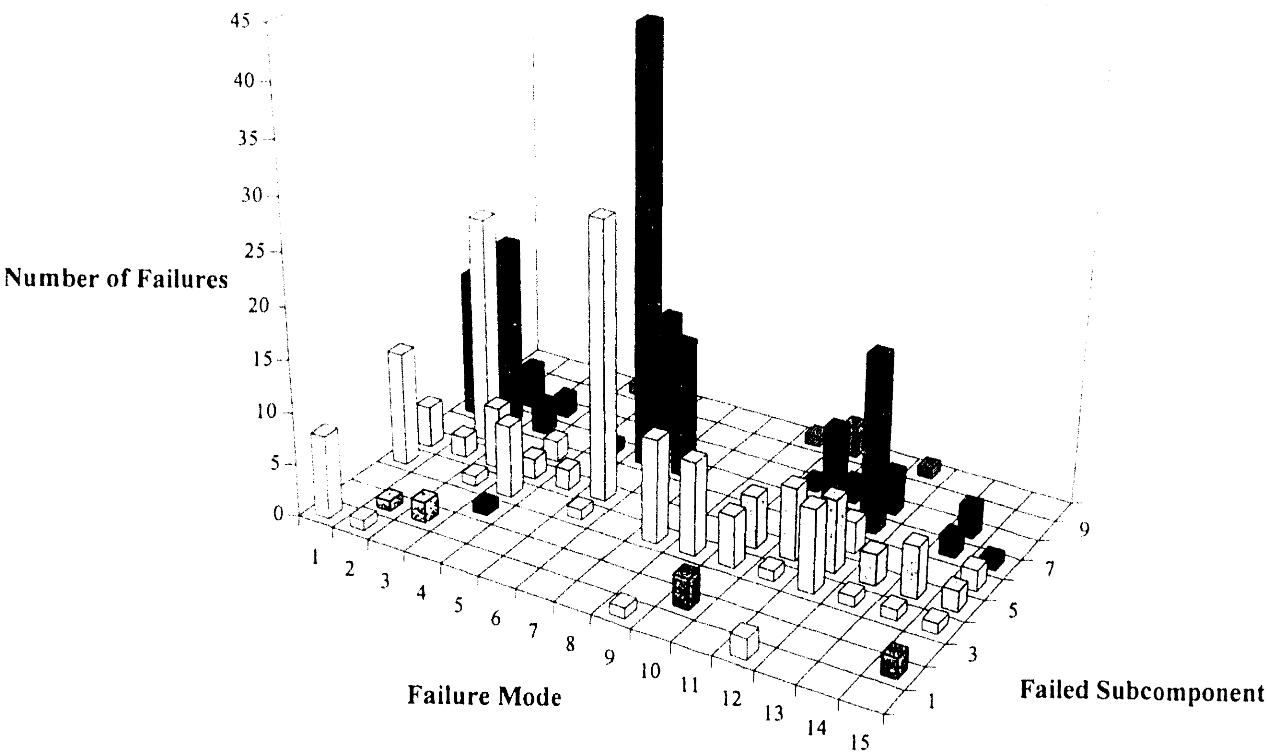
A total of 19% of all reports had both an unidentified subcomponent and failure mode. The only significant combination of identified subcomponent/failure mode noted was normal wear of the heater elements (17% of the reports with identified subcomponents and failure modes); normal wear of "other" components (9%) and open-circuiting of the heater element (8%) were also noted (see Figure 3-23).

3.6.2.3.4 Miscellaneous Relays

A total of 89 reports were applicable to miscellaneous relays of all manufacturers. None of these reports was the result of maintenance or testing activities. A total of 45% of the reports failed to identify the problematic subcomponent. A total of 40% were associated with failure of the relay coil; the remaining 15% of the reports were distributed among other subcomponents.

A total of 15% of all miscellaneous relay failures (all manufacturers) were associated with a loss of calibration of the relay, 14% were caused by open circuits, and 12% were related to electrical faults (short circuits). A total of 23% of the reports had unidentified failure modes.

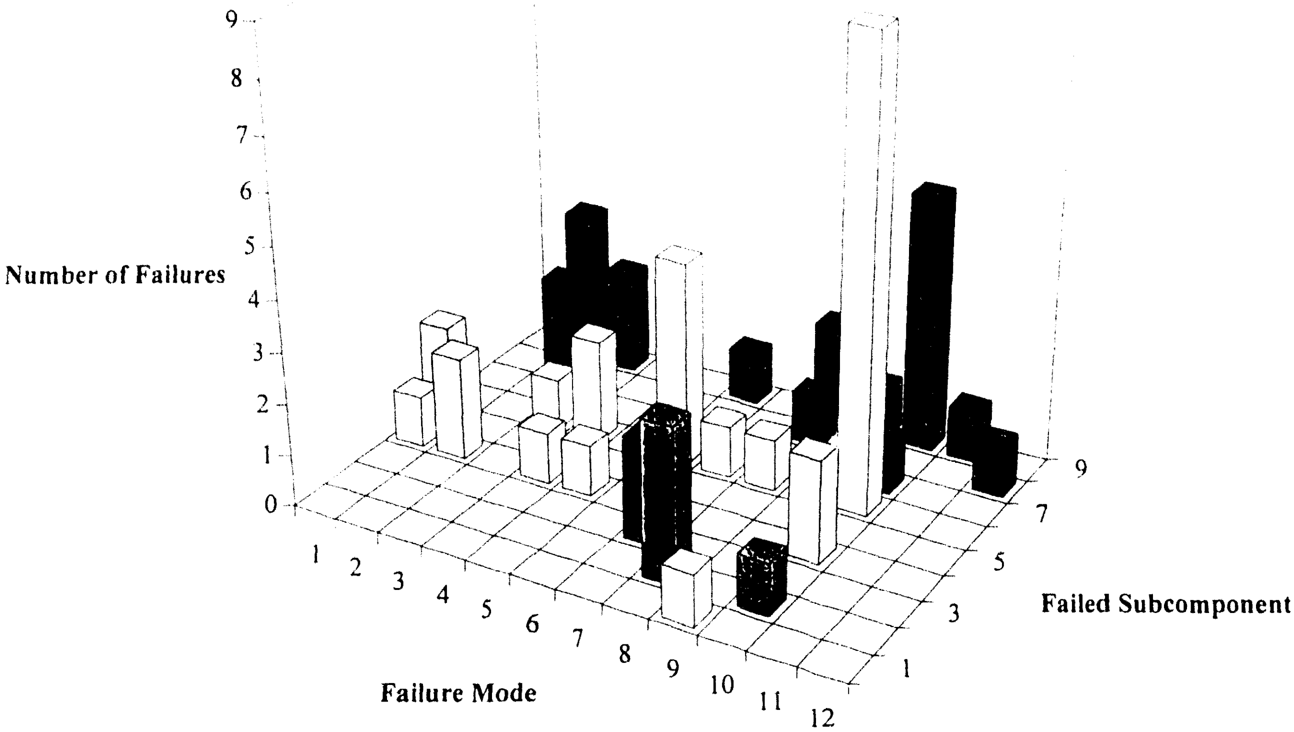
Of all reports, 10% had both an unidentified failed subcomponent and failure mode. The most significant combinations of identified subcomponent/failure mode include open circuits of the coil (28% of all reports with identified failed subcomponent and failure mode) and short circuits of the coil (21%). See Figure 3-24.



Based on 297 Reports

Number	Failure Mode	Failed Subcomponent
1	Unknown	Unknown
2	Dirty/pitted/corroded	Connections
3	Deformed/broken	Insulation (wiring)
4	Heat damage	Coil
5	Cyclic fatigue	Contact mechanism
6	Binding/sticking	Contact surfaces
7	Inadequate lubrication	Auxiliary contacts
8	Open circuit	Interlock
9	Fault	Hardware
10	Loose	Other
11	Out of adjustment/alignment	
12	Normal wear	
13	Cracked	
14	High electrical resistance	
15	Other	

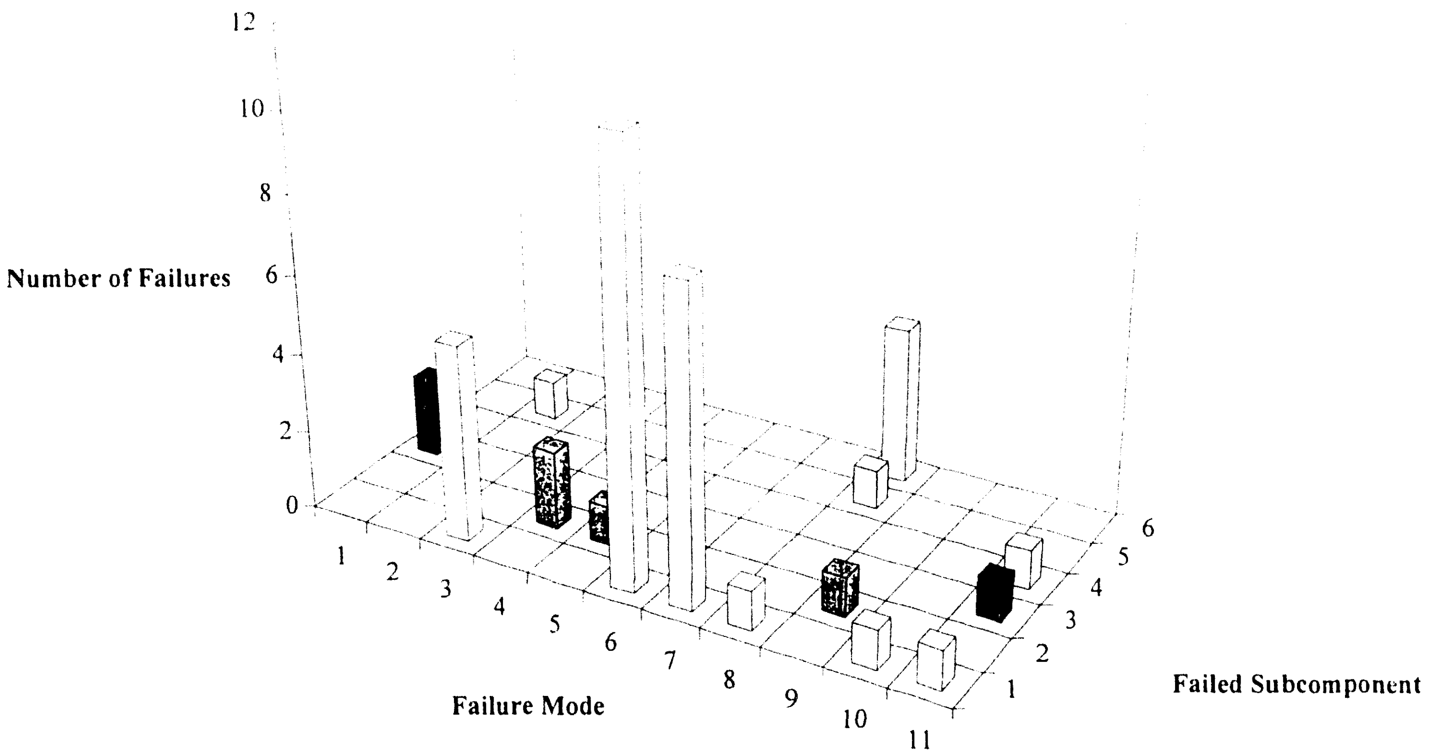
Figure 3-22. Significant Starter and Contactor Subcomponent/Failure Mode Combinations (All Manufacturers).



Based on 54 Reports

Number	Failure Mode	Failed Subcomponent
1	Dirty/pitted/corroded	Trip device
2	Deformed/broken	Connections
3	Heat damage	Coil
4	Cyclic fatigue	Contact mech.
5	Binding/sticking	Contact surfaces
6	Open circuit	Overload heater
7	Fault	Bimetallic/eutectic device
8	Loose	Hardware
9	Out of adjustment/alignment	Other
10	Normal wear	
11	Cracked	
12	High electrical resistance	

Figure 3-23. Thermal Overload Relay Subcomponent/Failure Mode Combinations (All Manufacturers).



Based on 39 Reports

Number	Failure Mode	Failed Subcomponent
1	Dirty/pitted/corroded	Coil
2	Deformed/broken	Contact mechanism
3	Heat damage	Contact surfaces
4	Cyclic fatigue	Auxiliary contacts
5	Binding/sticking	Hardware
6	Open circuit	Other
7	Fault	
8	Loose	
9	Out of adjustment/alignment	
10	Normal wear	
11	High electrical resistance	

Figure 3-24. Miscellaneous Relay Subcomponent/Failure Mode Combinations (All Manufacturers).

3.6.2.3.5 Wiring

A total of 48 reports were applicable to wiring. Of these reports, 27% (13) were the result of maintenance or testing activities. None of the reports failed to identify the problematic subcomponent. A total of 63% were associated with failure of the wiring termination or connector; 20% were related to failure of the insulation, 14% were caused by the conductor failing, and the remaining reports were associated with other subcomponents (such as wiring harnesses and other hardware).

With respect to failure modes associated with wiring, 37% of all wiring failures were caused by loosening, 37% were caused by broken or deformed subcomponents, and 14% were caused by electrical faults (short circuits). None of the reports had unidentified failure modes.

The most significant combinations of identified subcomponent/failure mode (Figure 3-25) were loose connections/terminations (37% of all reports) and deformed or damaged insulation (17%).

3.6.2.3.6 Other MCC Components

Because of the low number of failures reported for MCC control transformers, fuse holders, switches, and terminal blocks (all manufacturers), no specific inferences can be drawn concerning the reliability of their subcomponents or any associated failure modes. This relative lack of failure reports (with respect to other MCC components), however, might also be interpreted as an indication that no significant problems with these components exist.

3.6.2.4 Subcomponent Failure Analysis (Manufacturer Specific)

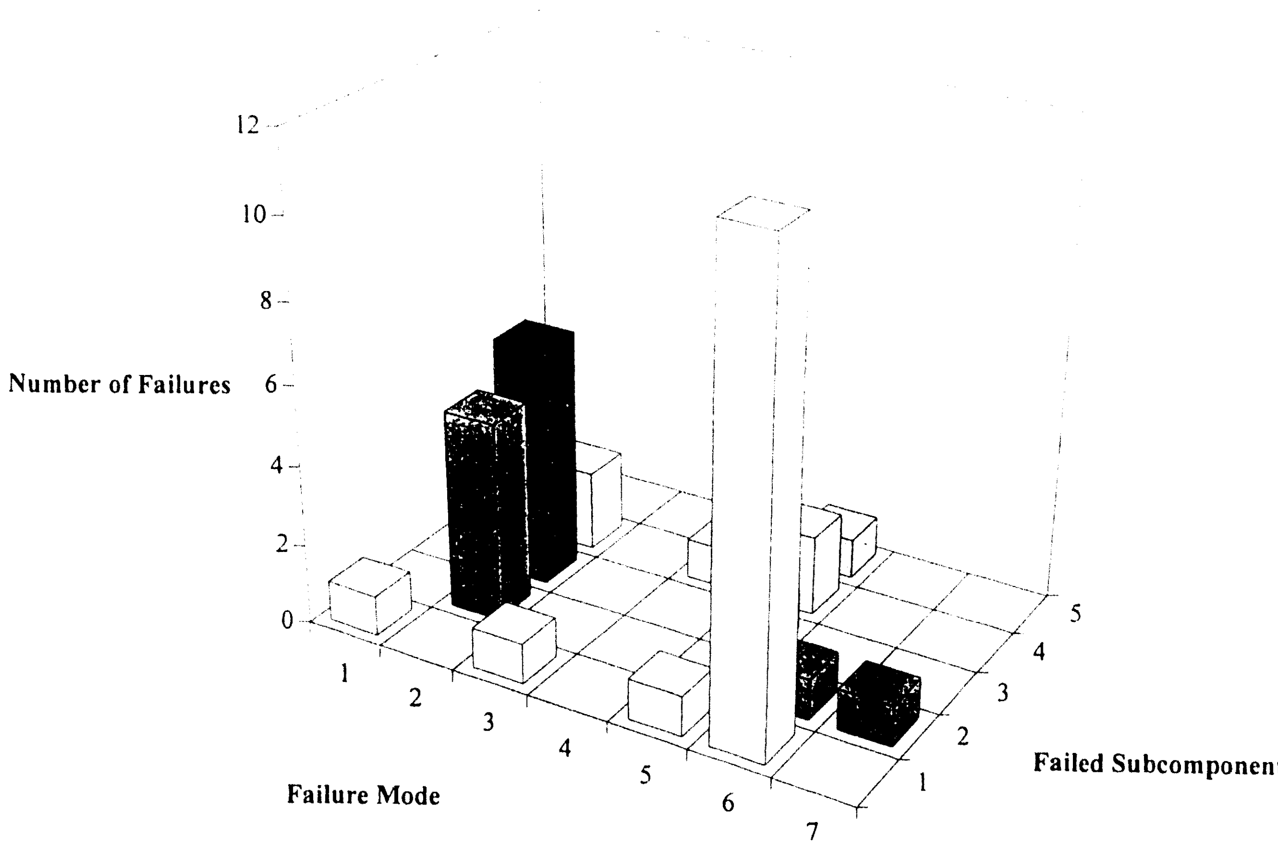
As previously indicated, the subcomponent and failure modes data associated with each individual manufacturer of MCC equipment were evaluated; only four of the manufacturers identified in Section 3.6.2.2 had subcomponent data that were sufficient to support this analysis. The findings noted for these four classes of equipment are described in the following subsections.

3.6.2.4.1 General Electric

3.6.2.4.1.1 GE Molded-Case Circuit Breakers

There were 109 reports identified as applicable to GE MCC breakers; of these reports, only one failure was identified as being maintenance-induced. Failures for GE breakers by were distributed by subcomponent as follows: 29% were caused by unidentified causes, 17% were caused by failure of the operating handle/linkage, 12% were caused by the overcurrent trip device, and 11% were attributed to the operating mechanism.

With respect to failure modes, 27% of the GE breaker failures were caused by normal wear/end of life, 20% were caused by unidentified causes, 15% were caused by loss or inability of the breaker to be calibrated, and 9% each were caused by broken/deformed and binding or sticking parts.



Based on 35 Reports

Number	Failure Mode	Failed Subcomponent
1	Dirty/pitted/corroded	Connections
2	Deformed/broken	Terminations
3	Heat damage	Insulator
4	Open circuit	Conductor
5	Fault	Other
6	Loose	
7	Other	

Figure 3-25. Wiring Subcomponent/Failure Mode Combinations (All Manufacturers).

Thirty-seven of the 108 failure reports (34%) had either an unidentified subcomponent or failure mode. Based on the remaining 71 reports, the most frequent subcomponent/failure mode combinations for these breakers were "normal" wear and loss of adjustment of the operating handle/linkage (7% each), normal wear of the internal operating mechanism (7%), and loss of calibration of the overcurrent trip device (6%).

3.6.2.4.1.2 GE Starters/Contactors

A total of 152 reports were found concerning GE starters/contactors. Four of these failures (3%) were identified as being maintenance-induced. Failures were distributed by subcomponent as follows: 52% (77) of the noted failures were related to auxiliary contacts, 16% were caused by failure of the main contactor mechanism, 11% were caused by coil failures, and 9% were associated with main contact surfaces.

Predominant failure modes were binding and sticking (26% or 38 reports), dirt, corrosion, or pitting (15%), inadequate lubrication (9%), and unidentified causes (10%).

Fifteen of the 148 reports (10%) had either unidentified subcomponents or failure modes. From the remaining 133 reports, the most significant combinations noted were binding or sticking of the auxiliary contacts (23%), inadequate lubrication of the auxiliary contacts (10%), deterioration of the main contact surfaces (9%), and deterioration of the auxiliary contact surfaces (8%).

3.6.2.4.1.3 GE Thermal Overload Relays

A total of 50 reports relating t[illegible]rload relay failures were located; one of these failures was maintenance-induced. 58% o[illegible] failures were caused by unidentified causes, 14% were caused by failure of the heater element, and 12% were caused by a variety of other subcomponents. In terms of failure modes, 52% (26) of the failures were caused by normal wear/end of life, 12% by subcomponents being out of adjustment, and 10% were caused by unidentified causes.

Because of the relatively high proportion of unidentified subcomponents and failure modes present in these reports, no failure mode versus subcomponent inferences can be drawn about GE overload relays in specific.

3.6.2.4.1.4 Other GE MCC Components

Because of the low number of failures recorded for GE MCC control transformers, miscellaneous relays, fuse holders, terminal blocks, switches, and wiring, no specific inferences can be drawn concerning these components.

3.6.2.4.2 Westinghouse

3.6.2.4.2.1 Westinghouse Molded-Case Circuit Breakers

A total of 116 reports related to Westinghouse MCC breakers were found; 6 of these failures (5%) were considered maintenance-induced. Failures were distributed by subcomponent as follows: 36% were associated with failure of the operating handle/linkage, 10% were caused by the overcurrent trip device, 9% were caused by the operating mechanism, and 29% were caused by unidentified causes.

With respect to failure modes, 38% of the failures were attributed to normal wear/end of life, 14% to unidentified causes, 10% to breaker components being out of adjustment, and 10% to broken/deformed parts.

A total of 35 of the 110 applicable reports had either an unidentified subcomponent or failure mode. Examination of the remaining 75 reports indicated the following subcomponent/failure mode combinations as being most significant: normal wear of the operating handle/linkage (27%) and breakage or deformation of operating handle parts (8%).

3.6.2.4.2.2 Westinghouse Starters/Contactors

A total of 93 reports were associated with Westinghouse starter/contactor assemblies; 2 of these reports were identified as being maintenance-induced. Failures were distributed by subcomponent as follows: 27% were caused by failure of the main contactor mechanism, 23% were associated with auxiliary contacts, 16% were caused by failure of the contactor coil(s), and 10% were caused by contamination, pitting, or corrosion of the main contact surfaces.

With regard to failure modes, 25% of the failures were attributed to normal wear/end of life, 19% to binding and sticking of the mechanism, 10% to breaker components being out of adjustment or alignment, 10% to unidentified causes, and 9% to dirty, pitted, or corroded subcomponents.

Eleven of the reports (12%) did not identify either the failed subcomponent or failure mode. The remaining 80 reports indicated that the most significant combinations of subcomponent/failure mode were normal wear of the auxiliary contacts (9%), binding or sticking of the main contactor mechanism (9%), and normal wear of the main contactor coil(s) (8%).

3.6.2.4.2.3 Westinghouse Thermal Overload Relays

A total of 75 reports applicable to Westinghouse thermal overload relays were generated. Of these 75 reports, 15 (20%) were maintenance-induced. Failures were distributed by subcomponent as follows; 19% were caused by failure of the heater elements, 6% were caused by contact surfaces and mechanisms, and 22% were related to other subcomponents. A total of 49% of the failures were associated with unidentified subcomponents.

Predominant failure modes of the Westinghouse thermal overload relays were as follows: 30% of the failures were attributed to normal wear/end of life, 7% to electrical open circuits, 7% to broken/deformed parts, and 33% to unidentified causes.

A total of 39 of the 60 applicable reports failed to identify either the failed subcomponent or the failure mode. No statistically significant subcomponent/failure mode combinations were identified because of the small number of remaining reports (21).

3.6.2.4.2.4 Other Westinghouse MCC Components

Because of the low overall number of failures recorded for Westinghouse MCC control transformers, miscellaneous relays, fuse holders, terminal blocks, wiring, and switches, no specific inferences can be drawn concerning these components.

3.6.2.4.3 Gould/ITE

3.6.2.4.3.1 Gould/ITE Molded-Case Circuit Breakers

A total of 128 reports applicable to Gould/ITE MCC breakers were found. Six of these failures (5%) were considered maintenance-induced. Failures were distributed by subcomponent as follows: 32% were caused by unidentified causes, 18% were caused by failure of the breaker operating mechanism, 15% were associated with the trip mechanism, and 12% were caused by the overcurrent trip device.

With respect to failure modes, 30% of the failures were caused by unidentified causes, 12% to normal wear/aging, 11% to inadequate lubrication, 10% to binding/sticking, and because of subcomponent loosening.

A total of 46 reports failed to identify either the affected subcomponent or failure mode. The remaining 76 reports indicate the following significant combinations of failed subcomponent and failure mode: inadequate lubrication of the internal operating mechanism (12%), binding or sticking of the trip mechanism (11%), and electrical faults (short circuits) associated with the trip device (10%).

3.6.2.4.3.2 Gould/ITE Starters/Contactors

A total of 55 reports applicable to Gould/ITE starters/contactors were found. Two of these failures (4%) were considered maintenance-induced. Failures were distributed by subcomponent as follows; 26% were caused by failure of the main contactor coil, 21% were related to auxiliary contact assemblies, 13% each were caused by failure of the main contactor mechanism and interlock mechanism, and 6% were caused by miscellaneous hardware associated with the device.

Analysis of the starter/contactor failure modes produced the following results: 25% of the failures were caused by binding or sticking, 17% to subcomponent loosening, and 11% to contamination, pitting, or corrosion. A total of 19% of the reports had unidentified failure modes. Eleven reports failed to identify either the affected subcomponent or failure mode. The remaining 42 reports indicated the following significant combinations of failed subcomponent and failure mode: binding and sticking of the auxiliary contact mechanism (14%), binding or sticking of the contactor interlock mechanism (10%), and loosening of the starter/contactor hardware (10%).

3.6.2.4.3.3 Other Gould/ITE MCC Components

Because of the low overall number of failures recorded for Gould/ITE MCC overload relays, control transformers, miscellaneous relays, fuse holders, terminal blocks, wiring, and switches, no specific inferences can be drawn concerning these components.

3.6.2.4.4 Cutler-Hammer

3.6.2.4.4.1 Cutler-Hammer Starters/Contactors

A total of 23 reports related to Cutler-Hammer starters and contactors were identified; none of these reports was considered maintenance-induced. Failures were distributed by subcomponent as follows; 30% were caused by problems related to the auxiliary contacts, 30% were caused by failure of the contactor coil(s), 21% were associated with the main contactor mechanism, and the remainder were the result of other/unidentified subcomponents.

Contaminated, pitted, or corroded contact surfaces, mechanism binding or sticking, or electrical faults each accounted for 17% of the total number of failures. The remainder of reports were distributed among the other failure modes.

No statistically significant subcomponent/failure mode combinations were identified for this component because of the overall low number (23) of reports.

3.6.2.4.4.2 Other Cutler-Hammer MCC Components

Because of the low overall number of failures recorded for Cutler-Hammer MCC breakers, overload relays, control transformers, miscellaneous relays, terminal blocks, fuse holders, wiring, and switches, no specific inferences can be drawn concerning these components.

3.6.2.5 Conclusions from NPRDS Review

As indicated above, the NPRDS data are not specific to age-related information. In many instances, the scope was limited with respect to the number of plants and the time period reported. Despite these limitations, several observations can be made about the various classes of MCC components evaluated.

In general, breakers and starters/contactors are the MCC components subject to the highest rate of failure; this can be substantiated by the high percentages of reports associated with these components (35% and 32% for breakers and starters/contactors, respectively) in relation to other MCC components. This behavior varies significantly, however, as a function of the manufacturer of the equipment in question. For example, Gould/ITE MCCs appear to exhibit the highest rate of breaker failure relative to other components within the same equipment; more than 53% of all reports related to Gould/ITE MCCs concerned breaker failures. This is in sharp contrast to Cutler-Hammer equipment, in which only 9% of the reports were related to breakers. Similarly, starter/contactor reports range from a low of 23% (Gould/ITE) to a high of 52% (Cutler-Hammer). Hence, breaker and starter/contactor failures appear to be of varying concern based on the manufacturer of the equipment installed. This also appears to be true of overload relays. These components had the third highest percentage of failures (for all manufacturers combined), yet this percentage varied from a low of 6% (for Gould/ITE) to a high of 22% (Westinghouse).

Whether considering individual components or all components as a whole, detection of component failures was in general most prevalent during operations. A few components (such as overload relays and switches) had smaller percentages of their total number of failures detected during operation; however, these were the exception. This result seems to indicate that in general, substantial portions of MCC component failures (i.e., 39% of all component failures) go undetected until 1) the component is called on to perform its required function(s), or 2) the functionality of the component is interrupted as a result of the failure. This may stem in part from the difficulty present in accurately assessing the condition of certain components (during inspection, maintenance, or testing), or the lack of application of maintenance, testing, or inspection techniques which are effective at identifying the types of problems which ultimately result in component failure.

From the analysis of the affected subcomponent(s) and failure modes associated with the failures of each MCC component, the following observations were made:

1. Breakers. As indicated in Section 3.6.2.3.1, wear of the operating handle/linkage accounted for the largest single percentage of identified failures for all manufacturers (12%), followed by wear and inadequate lubrication of the internal operating mechanism (11%). Little variation from this result was noted in the analysis of the results for GE and Westinghouse equipment; however, the results for Gould/ITE MCC breakers showed that binding, sticking, and inadequate lubrication of the internal breaker mechanisms were predominant (collectively accounting for 23% of reports for which the subcomponent and failure mode was identified). Also noted for Gould/ITE equipment was the loss of calibration of the overcurrent trip device (10%). Failure of the operating handle/linkage did not appear to be significant for this manufacturer of MCC breaker. The data for the other equipment manufacturers (Cutler-Hammer, Klockner-Moeller, etc.) were not sufficient to support any inferences concerning subcomponent aging. Hence, for GE and Westinghouse equipment, additional attention to the breaker operating handle/linkage mechanism is warranted. Binding of the breaker internal operating mechanism (and/or deterioration of the lubrication) appears to be much more significant in the aging of the Gould/ITE MCC breakers.

2. Starters/Contactors. As noted in Section 3.6.2.3.2, binding and sticking of the auxiliary contact assemblies accounted for the largest single percentage of identified failures for all manufacturers (14%), followed by binding and sticking of the main contactor mechanism (9%). Contamination, pitting, or corrosion of the main and auxiliary contact surfaces collectively accounted for 13% of the identified failures. These results were comparable to those noted specifically for General Electric

equipment; however, for Westinghouse starters/contactors, wear of the main contactor coil was indicated (8% of the reports for Westinghouse equipment), and binding or sticking of the contact interlock mechanism and loose hardware were noted for Gould/ITE equipment (each accounting for 10% of the Gould/ITE reports). Hence, binding, sticking, and lubrication of the auxiliary contact mechanism associated with all manufacturers' MCCs is significant and warrants additional consideration. Binding of the main contactor and interlock mechanism as well as deterioration of the main and auxiliary contact surfaces may also be significant factors (depending on manufacturer).

3. Thermal Overload Relays. As described in Section 3.6.2.3.3, the only significant combination of failed subcomponent/failure mode was normal wear of the overload heater elements (17% of reports with identified subcomponent and failure mode). No other combinations occurred with sufficient frequency to support any meaningful inferences. The overload relay data present for each of the specific manufacturers were likewise insufficient for these purposes.

4. Miscellaneous Relays. As indicated in Section 3.6.2.3.4, the majority of failures of relays used in MCCs were associated with the relay coil; 28% and 21% of the failure reports (with identified causes) were the result of open and short circuits of the coil, respectively. No other combinations occurred with sufficient frequency to support any meaningful inferences. The relay failure data present for each of the specific manufacturers were likewise insufficient for these purposes.

5. Wiring. Loose connections and terminations accounted for 37% of all identifiable failures (see Section 3.6.2.3.5); this was followed by damaged or deformed insulation (17%). No other significant combinations were noted. Because of the generic nature of wiring and terminations, this result is deemed to be applicable to all manufacturers of MCC equipment.

In general, other MCC components (i.e., terminal blocks, fuse holders, and switches) make up a small percentage of the failures noted (both for each specific manufacturer and for all manufacturers collectively). Hence, it can be assumed that the aging of these components is not a significant cause of MCCs failing to perform their required functions.

Maintenance-induced events accounted for varying percentages of the total number of failure events recorded in each category (i.e., component, subcomponent, failure mode, and manufacturer); although not considered an aging mechanism per se, these events do represent a factor to be considered in the aging of the equipment. A high incidence of maintenance-related degradations and/or failures may result from several factors, including a high degree of difficulty involved with performing the task, incorrect or inadequate maintenance procedures, maintenance being conducted too frequently, and erosion of the skill/knowledge level of personnel maintaining the equipment. The only component for which a significant fraction of maintenance-induced events were noted was MCC wiring (27% of all reports related to wiring); this indicates that a relatively high propensity for damage (or incorrect installation) of the wiring during or after maintenance or testing exists.

3.6.3 Evaluation of LER Data

NRC LERs are another source of MCC failure and degradation data. LERs are issued by nuclear plant operators when equipment failures and plant operating events meet the reporting requirements specified in 10 CFR 50.73.[3.108] As with NPRDS data, LERs are not oriented directly toward recording data related to component aging. In addition, the criteria for issuance of an LER do not encompass all component failures (especially those of little or no consequence to plant safety). Hence, evaluation of LER data provides only a partial picture of failure information; accordingly, the data may or may not be representative of general equipment failure behavior. LER data can be used, however, as support for the findings derived from other data sources (such as NPRDS), as well as for verification of postulated aging mechanisms.

The LERs used in this analysis covered the period from early 1980 through early 1992. The abstracts of approximately 600 LERs were identified via keyword search of the LER database maintained by Oak Ridge National Laboratory. Because of the structure of the LER database, a variety of keywords (including MCC, MCCB, starter, contactor, relay, and control transformer) were used in an attempt to locate all of the pertinent reports. Each of the reports generated by this search was individually reviewed; in cases where the applicability of a given report to a topic could not be reliably determined, the report was discarded. Of the 600 reports reviewed, 47 were ultimately retained. These reports were then categorized by component and subcomponent and failure mode; categorization by manufacturer was not practical because of the lack of consistent component manufacturer data, as well as the low number of total reports. The results of this analysis are tabulated in Table 3-6 and shown in Figures 3-26 through 3-28. Detailed analyses of the LERs (for each MCC component) are included in Sections 3.6.3.1 through 3.6.3.10 below.

3.6.3.1 MCC Structural Components (Including Metal Housing, Bus Structure, Terminals, and Disconnects)

The data contained in the LER database described seven events, from six separate plants, related to the MCC structural components. Two events involved the misalignment of a cubicle door, whereby the door would not shut properly, causing the tripping of an auxiliary transformer and the binding of the interlock mechanism, respectively. Five of the events pertained to the bus bar and power stabs and are broken down as follows: two of these five were caused by inadequate contact between the stabs and bus bars (coupled with dust in one event), two failures were caused by high resistance electrical connections, and one failure was maintenance induced where the cubicle had not been properly secured and latched. No failures of the metal housing itself were noted.

3.6.3.2 Molded-Case Circuit Breakers

The data contained in the LER database covered 14 plants during the period of the search. A total of 20 events occurred. Of these, five failures (25%) were caused by "normal" wear-out of the component, five (25%) were caused by loose connections on the breaker, three caused high resistances leading to overheating or arcing of the breaker (one of which was a defective internal connection), one (5%) was maintenance induced upon installation, causing binding of the undervoltage device cradle actuator blade against the breaker case; two failures (10%) were caused by an internal mechanical defect/failure of the mechanical latch, two originated from internal electrical defects, and the last three (15%) were attributed to malfunctioning with no stated source for the failures.

3.6.3.3 Magnetic Starters/Contactors

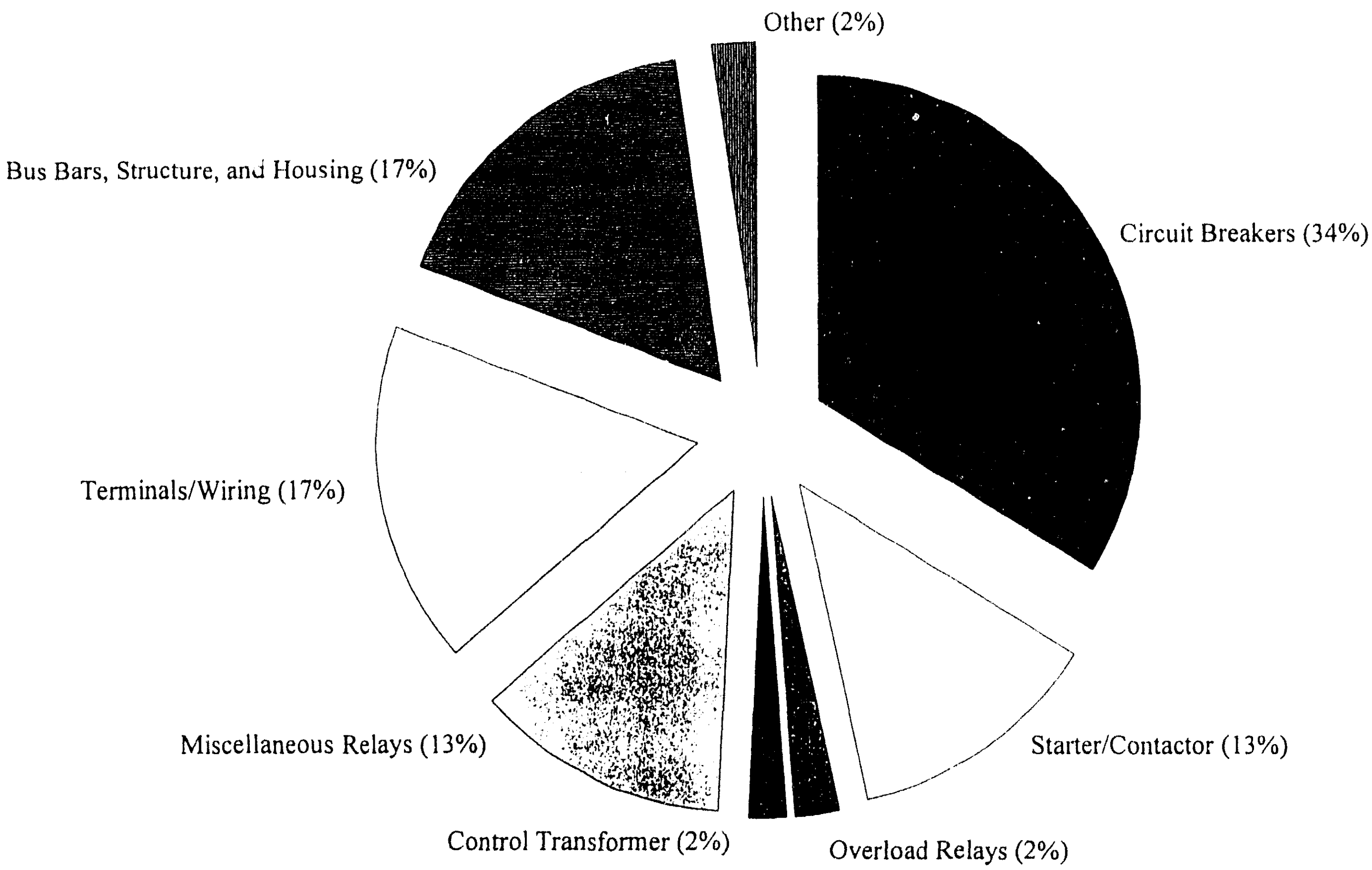
Ten reports were located relating to magnetic starters and contactors. Of these ten reports, six (60%) were caused by binding or sticking of some portion of the starter/contactor mechanism, and one failure each was attributed to normal end of life, heat damage, loss of adjustment, and unknown causes.

Table 3-6. Licensee Event Report (LER) Data, Motor Control Centers (All Manufacturers)

Failed Component	Failure Mode (see definitions below)													
	Total	1	2	3	4	5	6	7	8	9	10	11	12	13
Circuit Breaker	**16**	0	0	0	**5**	**5**	0	0	0	**3**	0	**1**	0	**2**
Thermal Overload	**1**	0	0	0	0	0	0	0	0	0	0	**1**	0	0
Starter/Contactor	**6**	0	**4**	**1**	0	**1**	0	0	0	0	0	0	0	0
Miscellaneous Relays	**6**	**1**	0	**2**	**1**	0	0	0	0	**1**	0	**1**	0	0
Control Transformers	**1**	0	0	0	0	0	0	0	0	0	**1**	0	0	0
Terminal Blocks/Wires	**8**	0	0	0	**5**	0	0	0	**1**	0	**1**	**1**	0	0
Housing/Bus Bar/Stabs	**8**	0	**1**	**3**	0	0	0	0	0	**2**	0	**2**	0	0
Fuse Holders	**0**	0	0	0	0	0	0	0	0	0	0	**1**	0	0
Other	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0
		1	**5**	**6**	**11**	**6**	**0**	**0**	**1**	**6**	**3**	**7**	**0**	**2**

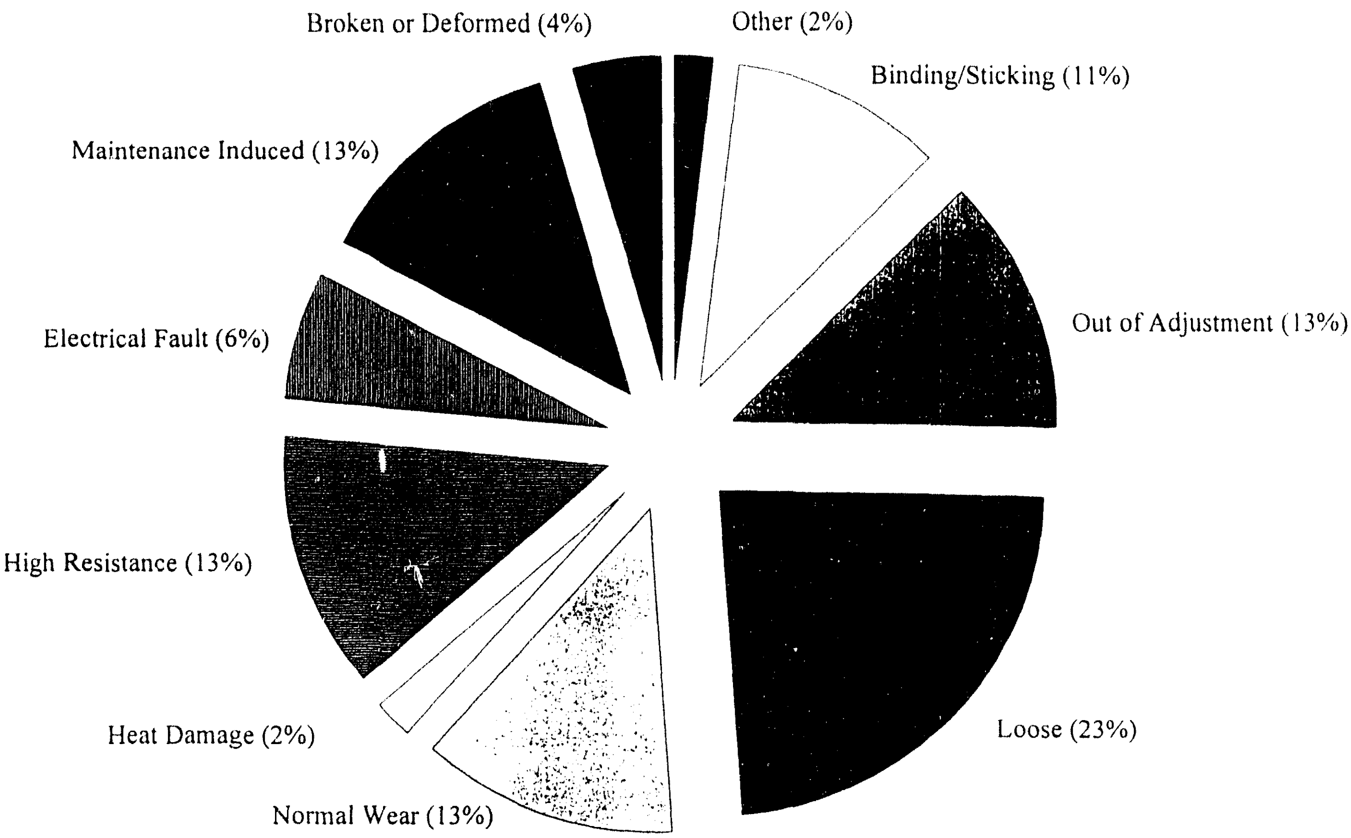
Failure Modes Defined

1 Inadequate/contaminated lubrication
2 Mechanical binding or sticking
3 Out of adjustment
4 Loose
5 Normal wear
6 Heat damage
7 Broken or deformed
8 Broken weld
9 High electrical resistance (including pitted/dirty contacts)
10 Electrical fault
11 Improper maintenance
12 Other
13 Unknown



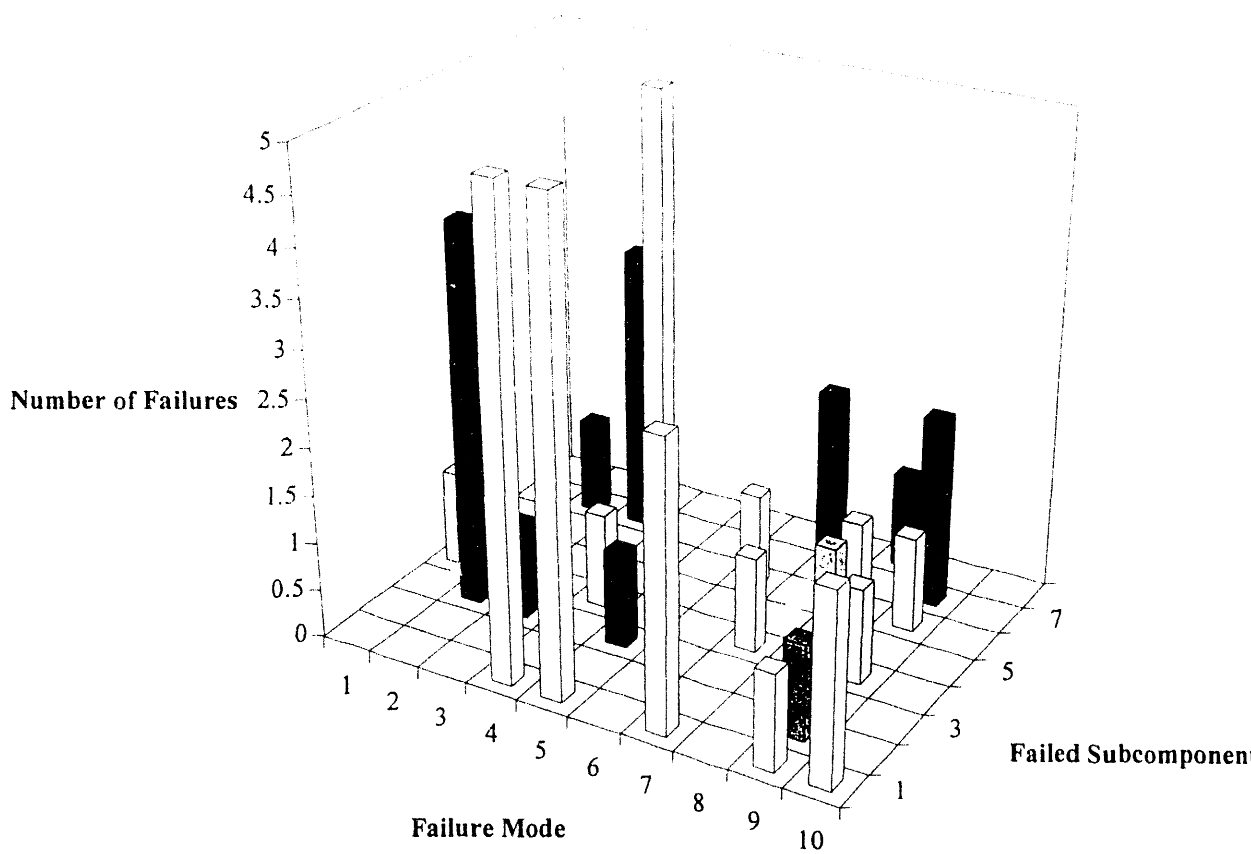
Based on 47 Reports

Figure 3-26. Licensee Event Report (LER) Component Failure Data (All Manufacturers).



Based on 47 Reports

Figure 3-27. Licensee Event Report (LER) Component Failure Modes (All Manufacturers).



Based on 47 Reports

Number	Failure Mode	Failed Subcomponent
1	Inadequate lubrication	MCCB
2	Binding	Contactor
3	Out of adjustment/calibration	Overload
4	Loose	Control transformer
5	Normal wear	Misc. relays
6	Heat damage	Wiring/terminations
7	Deformed/broken	Bus bar/power distribution
8	Weld failure	Other
9	High electrical resistance	
10	Fault	

Figure 3-28. LER Component/Failure Mode Combinations (All Manufacturers).

3.6.3.4 Thermal Overload Relays

The data in the LER search identified two failures pertaining to thermal overload relays. One failure was caused by improper installation in which the overload relay trip coils were not of sufficient capacity for the in-rush current. The failure to detect this deficiency was because of inadequate inspection and post-installation testing. The second failure was not attributed to a particular cause.

3.6.3.5 Miscellaneous Relays

The data in the LER search identified six failures of MCC relays from six separate units. Each of these six failures originates from six different failure mechanisms. These failures were caused by the following: high resistance leading to coil failure, dirty contacts leading to cycling, setpoint drift (attributed to unstated causes), a misaligned relay causing it to jam against its cover plate, and a mechanical defect where the movable contact became dislodged from its spring loaded mount; the final LER failure was maintenance induced, resulting in an incorrect tap setting following calibration.

3.6.3.6 Control Transformer

One LER was identified for control transformers; in this case, the transformer failed because of an electrical fault (ground) on the transformer winding. The cause of this fault was unidentified.

3.6.3.7 Terminal Blocks and Wires

The data in the LER search identified eight failures of the MCC terminal blocks and wires from eight separate plants. Five of these failures were caused by loose connections or terminal block mountings. One of the eight failures was caused by insulation breakdown, resulting in a trip. One failure was caused by a fault (short circuit) in the wiring, and the last failure was caused by improper installation of an MCC component, causing crimping of the wires.

3.6.3.8 Fuse Holders

One failure of the MCC control wiring system was noted; it was caused by metal fatigue of a fuse holder.

3.6.3.9 Switches

No failures related to locally mounted MCC switches were noted in the LERs.

3.6.3.10 Conclusions from LER Review

The following observations were noted with respect to the LERs:

1. With respect to MCC breakers, no one single subcomponent or failure mode was significant. Breakers identified in the LERs appeared to fail for a variety of reasons, the most numerous being normal wear and/or loosening of some subcomponent.

2. Binding or sticking of the starter/contactor mechanism (which may include the main contactor mechanism, auxiliary contacts, and interlock) appears to be the most significant source of MCC subcomponent failures.

3. The data for overload relays, control transformers, and miscellaneous relays show no clear trends with regard to affected subcomponents or failure modes.

4. Loose or broken wire connections and terminations resulted in a substantial percentage (13%) of the failures noted.

5. Maintenance-induced events constitute a sizable proportion (15%) of the failures reported.

It should be noted that the volume of LER data upon which these observations are based (47 reports total) is small in comparison with the number of NPRDS findings; hence, LER information must be evaluated in conjunction with the other data sources.

3.6.4 Studies Providing Industry-Wide Operating Experience for Motor Control Centers

3.6.4.1 NUREG/CR-5053: Operating Experience and Aging Assessment of Motor Control Centers

Brookhaven National Laboratory issued "Operating Experience and Aging Assessment of Motor Control Centers,"[3.29] which documents data from LERs, Nuclear Power Experience (NPE), NPRDS, and direct correspondence with several nuclear utilities over a 10-year period (1976-1986) for an assessment of MCC aging. The report characterized aging effects that, if left unchecked, could possibly lead to age-related degradation of MCC components, potentially impacting plant safety. This report discussed those maintenance practices relevant to MCCs, as well as their effectiveness at detecting significant component aging before a loss of functionality.

The predominant failure modes (defined in the study as the basic manner in which an MCC component fails) identified in NPRDS, based on the approximate percentage of total failures, include:

- Failure to close (23%)
- Open circuit (15%)
- Tripped (15%)
- Would not operate (14%)

- Failed to open (8%)
- Out of adjustment (7%)
- Loose connection (6%)
- Short/ground (6%)
- Unspecified (4%)
- Failure to trip (2%)

The predominant failure causes (defined in the study as the actual malfunction that led to component degradation or failure) identified in NPRDS, based on the approximate percentage of total failures, include:

- Unreported (21%)
- Other (19%)
- Sticking/foreign material (13%)
- Overheating (8%)
- Setpoint drift (8%)
- Mechanical failure (7%)
- Normal operation (7%)
- Binding (5%)
- Surface deterioration (5%)
- Mechanical interference (4%)
- Other system failure (3%)

Figures 3-29 and 3-30 illustrate the breakdown of subcomponent failures (for NPRDS and LER data, respectively) based on the research data of NUREG/CR-5053.[3.29] See also Figures 3-14 and 3-26.

The significant conclusions of this assessment are summarized below:

1. A majority of age-related failures in MCCs were attributed to circuit breakers and "miscellaneous" relays (collectively accounting for 50% of all reported failures noted). Starters/contactors and overload relays had the highest occurrence of failure among the remaining components.

2. The most frequent cause of MCC component failure was dirt and foreign materials, causing electrical devices to stick.

3. A significant number of failures were caused by wear during normal operation.

4. Failures were more prevalent in systems functioning intermittently (during normal plant operation or test conditions) rather than continuously.

5. LERs indicated that human error (improper maintenance, inadequate procedures, etc.) constituted approximately 15% of the total number of reports.

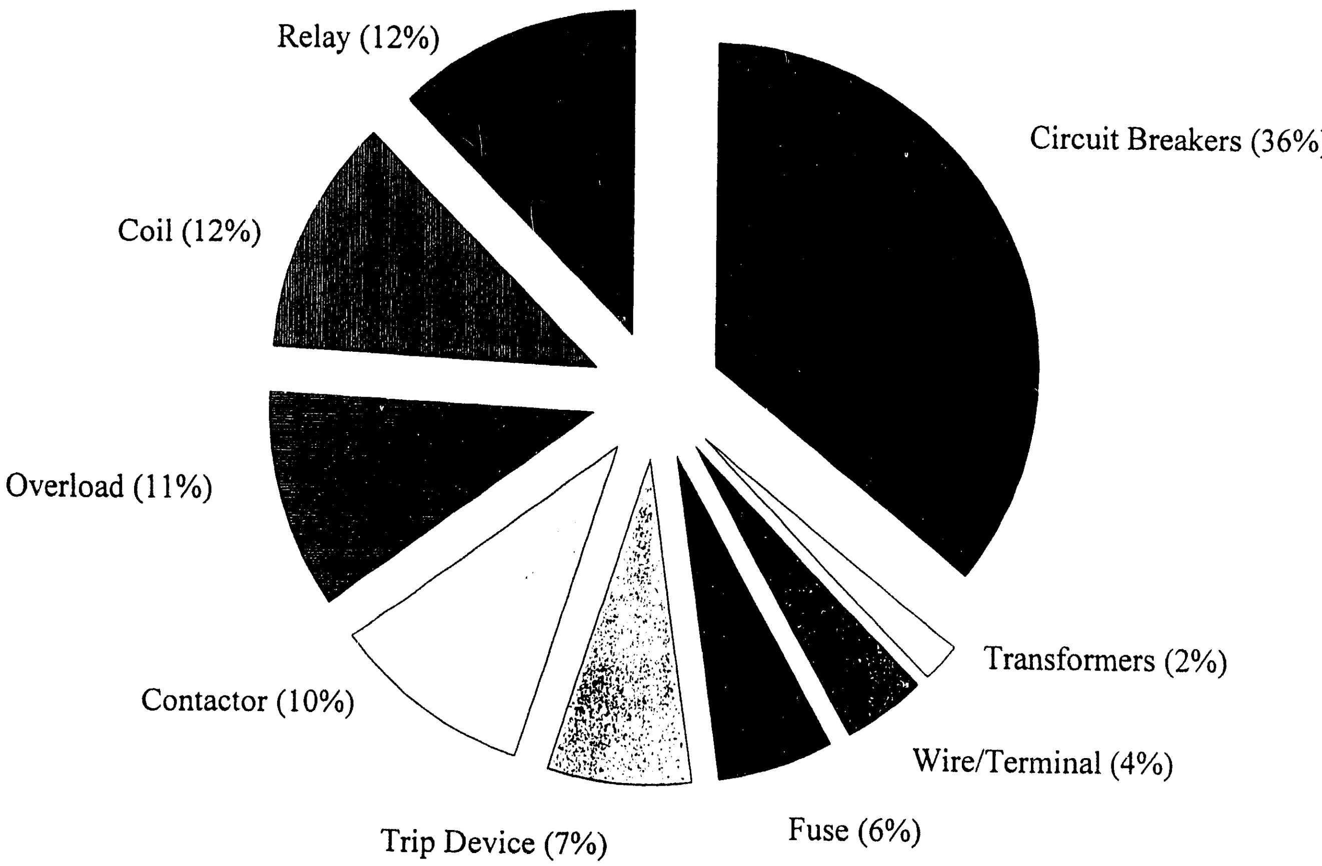


Figure 3-29. NUREG/CR-5053 Subcomponent Failures (NPRDS).

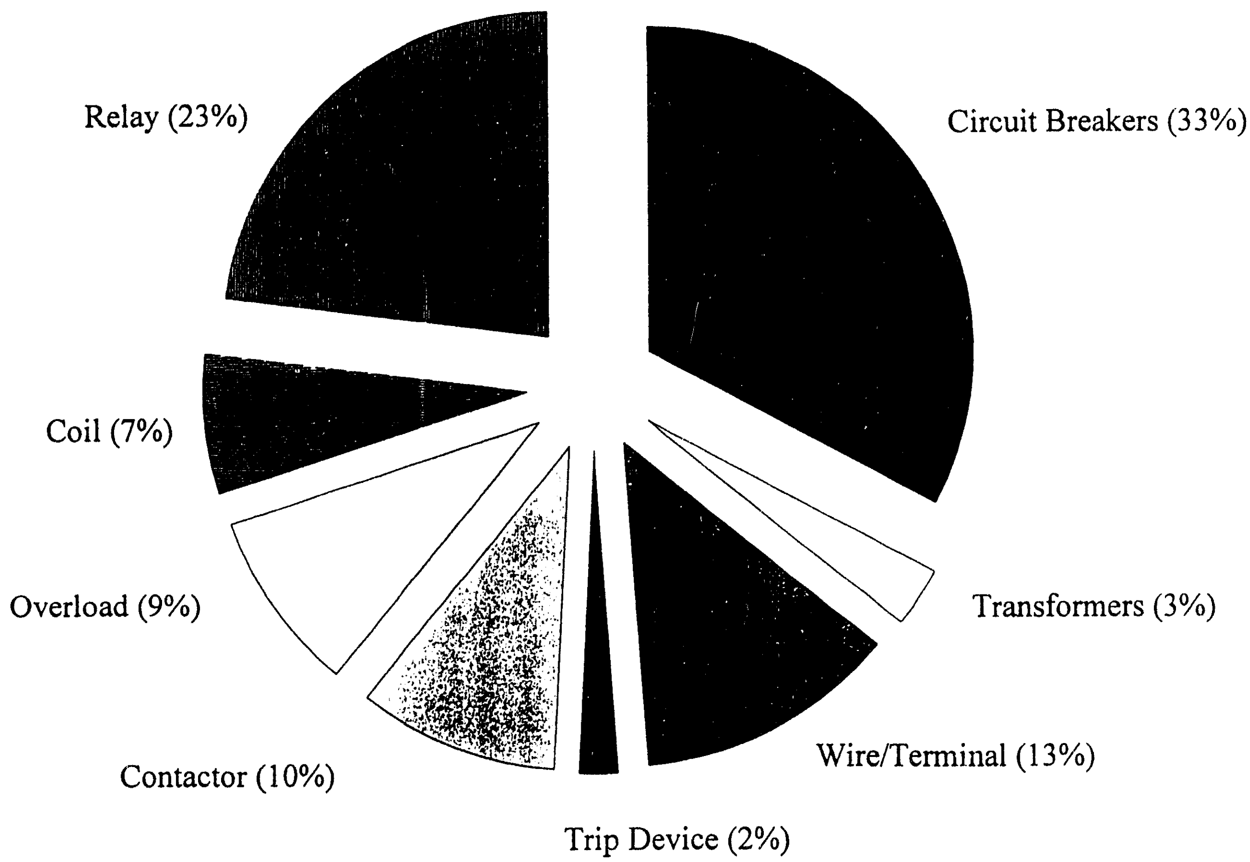


Figure 3-30. NUREG/CR-5053 Subcomponent Failures (LER and NPE).

3.6.4.2 Wyle Laboratories: Comprehensive Aging Assessment of Circuit Breakers and Relays for Nuclear Plant Aging Research Program, Phase II

"Comprehensive Aging Assessment of Circuit Breakers and Relays for Nuclear Plant Aging Research Program, Phase II"[3.30] assessed inspection, surveillance, and monitoring (ISM) techniques used for aging management of MCCBs. The MCCB ISM methods consisted of nine methods of testing currently used in the industry as well as eight additional advanced ISM techniques. The test specimens consisted of 11 breakers of varying ages from five different manufacturers that were solicited from various nuclear plant operators, non-nuclear facilities, and manufacturers. The current and advanced ISM methods used in the study are listed below.

Current ISM Techniques Used

- Visual Inspection
- Operation
- Pole Resistance
- Insulation Resistance
- Mechanical Actuation
- 100% Rated Current Hold-In
- 135% Rated Current Hold-In
- 300% Overcurrent
- Instantaneous Trip

Advanced ISM Techniques Used

- Infrared Pyrometry
- Infrared Scanning
- On-Contact Temperature
- Vibration Testing
- Acoustic Testing
- Ion Detection
- 600% Overload
- Dielectric

Significant findings of the assessment include the following:

1. Visual inspection and mechanical actuation of the 11 breakers proved beneficial in predicting problems more evident in other ISM techniques. Evidence of overheating and discoloration on some of the breakers was a somewhat reliable indication that other tests performed subsequently on the breaker would result in identification of a problem.

2. Pole resistance was measured in the as-received condition and after testing of the breaker was completed. Pole resistance showed a tendency to increase with age. In addition, a lack of operation appears to increase this resistance (i.e., the pole resistance of the breakers being tested decreased as the breakers were operated more).

In general, pole resistance variations or increases did not correlate with problems found in other ISM techniques.

3. The 100% and 135% rated current hold-in tests indicated somewhat expected results in that the 135% test produced temperatures averaging 10°F higher than those produced by the 100% test. No significant results or trends (individually or in correlation with other ISM methods) were noted.

4. The 300% overcurrent test resulted in a number of failures. An 18-year ITE KMB2F800 breaker failed on one pole from the distortion of the thermal trip element, which was traced to a loose connection. A 10-year old Klockner-Moeller NZMH6-100 circuit breaker failed to trip on all three poles because of interference with the thermal element from shrink tubing that was damaged by heating caused by the overcurrent. Visual inspection of one breaker showed failure attributed to overcurrent effects. In addition, the 300% overcurrent test showed an age-related trend.

5. The instantaneous trip testing yielded failure in four of the 11 breakers tested. The ITE KMB2F800 breaker failed because of overheating as it had during tests of its thermal trip unit. The Klockner-Moeller NZMH6-40 failed because of distortion of the trip pin. Two 18-year-old Westinghouse HFB31550 breakers failed as well. One of these failures was attributed to a missing spring in the trip mechanism. No cause was detected for the other failure.

The infrared pyrometry, infrared scanning, and on-contact temperature tests measured the temperature of various MCCB components under varying conditions. No significant differences between the devices at 100% rated current were noted in MCCBs during the infrared pyrometry test. No significant age-related degradation was noted in the infrared scanning test. The on-contact temperature test did, however, show a trend of increasing breaker temperature with age (based on measurement of pole temperature at 100% rated current).

Vibration and acoustic tests showed differences in vibration and acoustic properties between the various breakers used in the study. However, these varying properties could not be confidently attributed to age based on the diverse backgrounds of the breakers.

3.6.4.3 Environmental Testing of Class 1E AC Motor Control Center for Nuclear Power Plants

"Environmental Testing of Class 1E MCC for Nuclear Power Plants (NPP)"[3.109] reported on the testing of an MCC that was subjected to a high temperature/humidity environment and pressure pulses simulating the effects of a high energy steam line break in a BWR Mark I containment structure. This testing was based on an NRC requirement that plants with Class 1E MCCs located in the reactor building demonstrate the MCC's capability to withstand a DBE. The capabilities of the starter (to start or stop the motors) and motor operated valves were tested; the structural integrity of the MCC cabinet was also tested because of the possibility it might impair the functional capabilities of the components contained within.

Located within the MCC tested was a NEMA size 3 full voltage non-reversing starter and a NEMA size 2 full voltage reversing starter. The reversing starter failed to operate on demand after the temperature/high humidity test. Post-test inspection revealed a short circuit in the control power transformer caused by insulation breakdown. Epoxy-encapsulated control power transformers were installed and the MCC was retested. The results of the test were deemed acceptable. Subsequent similar tests proved that a dc MCC could also function in the post-accident atmosphere.

3.6.4.4 Nuclear Maintenance Applications Center (NMAC) Maintenance Guide on Molded-Case Circuit Breakers

EPRI NP-7410 (Volume 3) documents failure data for MCCBs used in nuclear plant applications. The study reviewed failure reports collected from NPRDS, the NRC (i.e., NUREGs, LERs, Information Notices, and Bulletins), and other sources. The results of this study (based on NPRDS data and shown in Figure 3-31) indicate the following:

1. The single, most common type of failure associated with MCCBs relates to the overcurrent trip device (37% of the reports analyzed). Damaged/broken parts, loss of calibration, improper setting, and degraded material properties were noted as applicable failure modes.

2. Nearly two-thirds (61%) of the failures noted in the data were attributable to the overcurrent trip device and operating mechanism (collectively). Dried lubricant, loss of alignment/adjustment, and worn or broken parts were cited as common failure modes.

3. Electrical devices (relays, switches, auxiliary contacts, etc.) and main current-carrying components (main contacts, arc chutes, and wiring terminals) each accounted for 12% of the failures. Failure modes for the electrical devices included coil failure and dirty/damaged contacts; those identified for the main current components were pitted, eroded, or dirty contacts, and damaged or otherwise degraded arc chutes.

4. Wiring and cable terminations were responsible for 10% of the failures; loose, dirty, mis-sized, and damaged wires, terminals, or connectors were cited.

5. There was little or no relation noted between insulation resistance and breaker performance or failure.

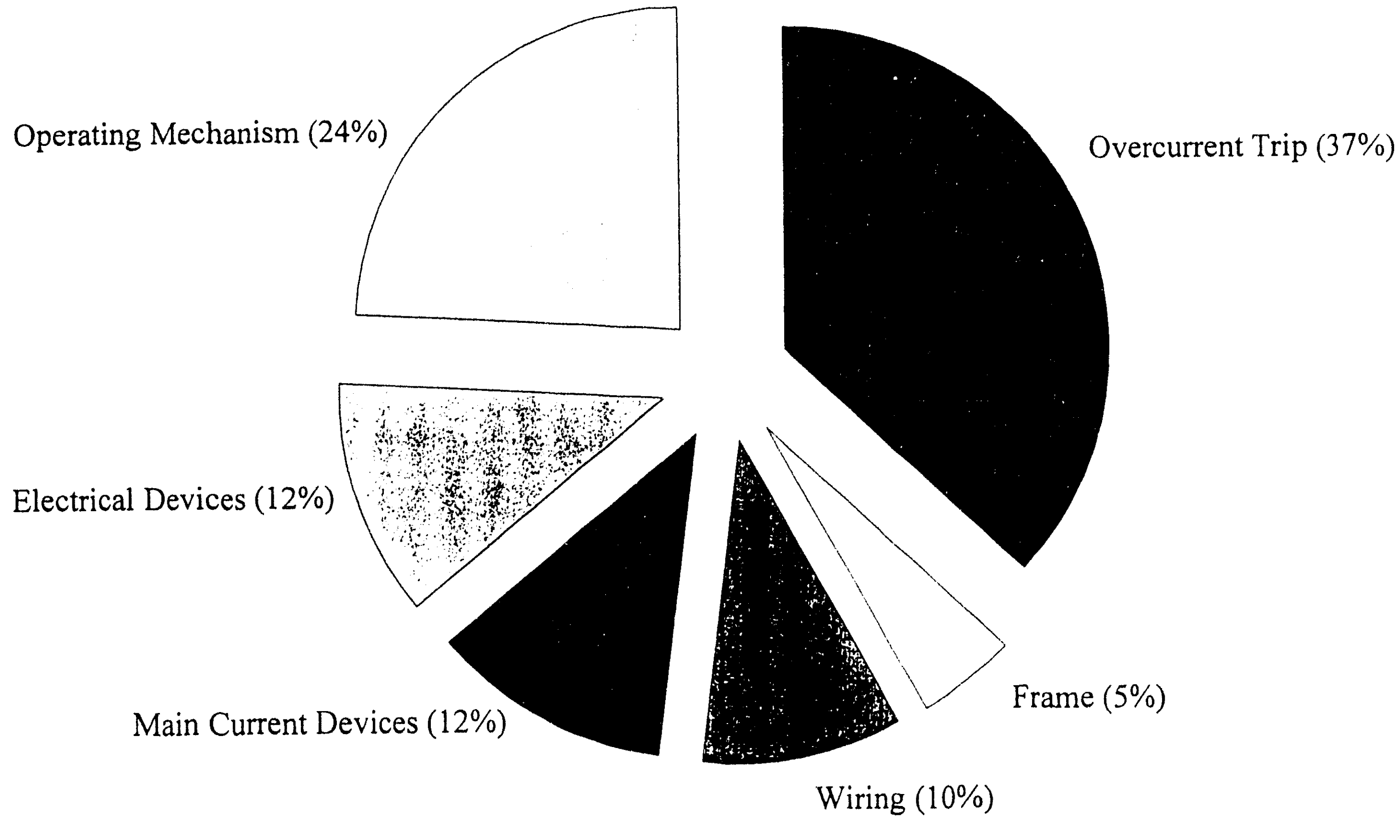


Figure 3-31. Breaker Subcomponent Failures (NPRDS) EPRI/NMAC Molded-Case Circuit Breaker Maintenance Guide.

3.6.5 Overall Conclusions Regarding Equipment Historical Performance

As discussed in the previous sections, three sources of historical information were used in this guideline to characterize historical MCC component performance: (1) NPRDS data, (2) LER data, and (3) information provided by previous analyses and reports relating to MCCs and their components. These sources each provide a somewhat different perspective on MCC component aging; however, because of differences in the scope and analysis techniques employed, direct comparison of the results is not possible and may produce misleading results. For example, the classification of several components, subcomponents, and failure modes varies between each of the documents; a subcomponent specifically identified and separated in one document may be grouped together with other similar subcomponents in another. Additionally, the percentage of failure reports (of the total reviewed) in which failed subcomponents and/or failure modes were unidentified is not provided in some documents; this introduces additional uncertainty into the comparison of results from those documents that did account for unidentified failures.

Despite these limitations, several generic trends and problems associated with specific MCC components (and operating conditions) can be identified in each of the sources described above; when viewed collectively, these sources provide the following insights into MCC aging and degradation:

1. Circuit breakers and starters/contactors failures are in general most prevalent; however, this result will vary based on the individual manufacturer of the equipment.

2. Starter/contactor mechanisms appear to be susceptible to mechanical binding and sticking. This appears to be especially prevalent in auxiliary contact assemblies, but may affect other mechanisms such as the main contactor and the forward/reverse contact interlock. Dirt, foreign material, and degraded or otherwise inadequate lubrication was often cited as the root cause of these failures.

3. Wear, misadjustment, or binding of the operating handle/linkage for MCC breakers (where equipped) was significant for several manufacturers of MCC (including General Electric and Westinghouse). Similarly, problems associated with the internal breaker operating mechanism (inadequate lubrication, binding, etc.) and overcurrent trip device (loss of calibration) were common to all manufacturers.

4. Exposure of MCCBs to fault conditions may damage the breaker internals (including the main current-carrying components) and may ultimately preclude its proper performance. Damage to the breaker appears to be a function of the magnitude, duration, and number of exposures to fault current.

5. Normal wear attributed to operation appears to be a commonly cited cause of component failure. The evaluation of wear as being normal or abnormal cannot realistically be conducted for each plant failure (especially in those components whose failure cause may not be readily determined, such as MCCBs); accordingly, many of the failures termed "normal" may, in fact, be caused by age-related degradation or other anomalous conditions. Hence, these reports lack the degree of specificity necessary to accurately assess their contribution to the failure rate/failure mode data for a given component.

6. Loose, damaged, or high resistance electrical connections and terminations appear to be a relatively significant cause of MCC failures; although wiring and wiring-related failures were assigned a separate category for the analysis, evidence of loose or high resistance electrical connections and terminations was present in all component categories. A large fraction of failures associated with wiring, terminations, and electrical connections appear to be caused by maintenance, inspection, or testing performed on the equipment prior to the failure.

7. Thermal overload relay heater elements may be somewhat susceptible to aging (compared to other parts of the overload relay), as these subcomponents were most often cited in overload relay failure reports.

8. Coil failure (open- or short-circuiting) appears to be a prevalent cause of miscellaneous relay failure.

9. Failures associated with control transformers, switches, fuse holders, and terminal blocks were far less numerous than those of the other components discussed above (breakers, starters, overloads, etc.) and do not appear to occur with sufficient frequency to warrant any special consideration.

3.7 References

3.1 NUREG-0212, "Standard Technical Specification for Combustion Engineering Pressurized Water Reactors," March 15, 1977.

3.2 NUREG-0103, "Standard Technical Specifications for Babcock and Wilcox Pressurized Water Reactors," U.S. Nuclear Regulatory Commission, Revision 4, October 31, 1980.

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4. APPLICABLE STRESSORS AND AGING MECHANISMS

4.1 Determination of Stressors Acting on Components

During operation, MCCs and MCC components are exposed to a number of stressors that can lead to deterioration. These stressors may act individually or in combination with one another to produce an aging mechanism. The following discussion of stresses is provided to facilitate development of the discussion of aging mechanisms and age-related degradation that may occur in MCCs. The potential stresses are:

- Temperature (ambient and internally generated)
- Voltage
- Mechanical/electrical cycling
- Non-seismic vibration
- Radiation

Although not directly producing stress, humidity, moisture, dirt, dust, and contaminants may enhance the effects of the stressors acting on the MCCs and can lead to deterioration of the MCC components.

Temperature

Temperature exposure causes thermal deterioration of organic materials used in MCCs as insulators and structural members of the control center subcomponents. Temperatures affecting MCCs are associated with the ambient environment and temperature rise from ohmic heating of the components internal to the MCC. Normally, control circuits (e.g., motor operated valve control circuits) of MCCs are de-energized or carry small currents; therefore, little ohmic heating occurs in the control circuit wiring. However, components such as control transformers, primary circuits (including molded-case circuit breakers), relays, and some control circuits (such as pump and fan control circuits) can produce substantial amounts of heat (because of continuous energization or current flow). Thermal deterioration has the potential for causing failures in the form of insulation breakdown, loss of structural integrity of organic materials (caused by thermally induced cracking), and deterioration of lubricants. Ohmic heating of primary circuit components can be appreciable especially if high resistance connections develop at terminations, bus junctions, disconnects, or main contacts. Development of a high resistance connection in a primary current-carrying path can cause rapid deterioration of the surrounding insulating material because of the heat generated. Generally, the ambient temperature surrounding MCCs is controlled between 21°C and 29°C [70°F and 85°F] and does not reach the 40°C [104°F] normal temperature limit assumed in MCC design and manufacturing standards. MCCs are infrequently located in areas having harsh environments. (See Section 3.5.2 for a discussion of harsh environments.)

Voltage

Stressors associated with the electrical functions of MCC components may also lead to age-related degradation. Electrical stressors are caused by extreme voltage gradients from overvoltage transients, spikes, or fault interruption. These stressors can result in short circuiting of components, flashover to ground or between phases, or restrike. Excessive voltages can lead to deterioration of the contact surfaces in magnetic contactors, relays, and circuit breakers, and provide a source of heat for thermal degradation. Fault currents and inductive surges/electrical transients can cause stresses that contribute to insulation breakdown and contact deterioration. Fault currents are especially degrading to MCCBs, causing damage to the main and arcing contact* surfaces, leading to contact burning and erosion. In addition, a high number of fault current interruptions can damage the insulating material in the arc-chutes and cause them to crack or break. Fault currents may cause annealing of the bimetallic trip elements found in MCCBs, changing their material characteristics and causing significant shifts in thermal element trip points.

Energization at normal design voltage levels does not significantly stress MCC components; however, it can cause problems when combined with dirt, humidity, or thermal deterioration. In MCCs, voltage and humidity can affect energized insulation that is dirty or deteriorated and cause surface tracking paths between phase and ground and adjacent phases. Moisture in the tracking path will allow larger leakage currents to flow. The leakage current flow will cause the moisture in the tracking path to evaporate; the leakage current will tend to remain constant such that the current density in the tracking path increases as moisture evaporates. This can result in localized burning of the insulation and ultimately insulation failure.

Thermally deteriorated insulation, when exposed to humidity and dirt, may lose not only its surface insulating properties (in the form of surface current tracking), but also its volumetric insulating properties. Thermally deteriorated insulation is most frequently brittle and prone to cracking. Leakage current, in addition to propagation across the surface of the insulation, may travel through the thickness of the insulation, eventually resulting in flashover. Reasonable inspection and care of primary insulation systems will detect surface and volumetric deterioration before it becomes severe.

Contaminants and moisture, in combination or acting independently, can result in deterioration of the MCC structural components; the housing may corrode and/or rust if exposed to contaminants and/or moisture such that the structural members and fasteners will weaken. In some instances, foreign matter may also affect the contact surfaces of relays, magnetic contactors, and MCCBs, potentially interfering with the performance of a component's required functions. Exposure to contaminants may degrade electrical components via increased friction (leading to wear), formation of electrical leakage paths, stiffening or freezing of moving components, hardening of lubricants, and embrittlement of non-metallic materials.[4.1]

Mechanical/Electrical Cycling

Mechanical cycling (a cycle being defined as one open and close operation) of MCC components places stress on these components and may cause them to degrade or deteriorate with time. Mechanical cycling can vary significantly within the MCC enclosure, because different loads are served through individual starter units and have differing cyclic operating requirements.

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* Separate arcing contacts are not used on all molded-case circuit breakers.

Table 4-1. Stressors, Aging Mechanisms, Potential Failure Modes

Stress	Intensifiers	Aging Mechanism	Age-Related Degradation	Potential Failure Mode	Comments
Ambient Temperature	Ohmic heating	Gradual deterioration of lubricants	Binding and high friction in mechanism	Stalled or slowed open or close operation of relays, contactors, or MCCBs	Generally a slow process; will occur more rapidly in elevated ambient temperatures
	Ohmic heating	Gradual deterioration of insulation	Loss of electrical and mechanical properties	Loss of insulating properties, potential for flashover of component insulation	Generally a slow long-term process
	Ohmic heating	Material embrittlement	Thermally induced cracking	Loss of structural integrity	
	Excessive ohmic heating from high resistance at primary circuit connections	Rapid deterioration of insulation, possible burning and fires	Rapid loss of electrical and mechanical properties	Flashover of insulation of power-carrying components	May occur relatively rapidly
	Ohmic heating, fault current	Annealing of bimetallic trip element	Significant shift in thermal element setpoint	Nuisance MCCB tripping or failure to trip when required	
Mechanical Cycling	Deteriorated lubricants	High friction between moving parts	Mechanical wear	Binding and slowing of contactor or MCCB mechanism	
	Operation under fault current or high electrical loads	Deterioration of components	Damage to contact surfaces, arc chutes, other components	Degraded function of MCCB	Inspection and appropriate maintenance after fault current operation to ensure continued function
Non-seismic Vibration		Cyclic wear/fatigue	Wear of components, loss of tolerances, misalignment	Friction or binding; component deformation or breakage of contactors or relays	

Table 4-1. Stressors, Aging Mechanisms, Potential Failure Modes (continued)

Stress	Intensifiers	Aging Mechanism	Age-Related Degradation	Potential Failure Mode	Comments
Voltage*	Dirt/humidity on insulator surfaces	Surface current tracking on insulation	Decreasing surface resistance, dry banding damage	Flashover	Generally a slow process; may be more rapid in presence of thermal deterioration; effects vary depending on configuration
	Thermal deterioration with humidity	Loss of volumetric and surface insulation properties	Increased surface and volumetric leakage currents	Flashover	Of concern for insulations in an advanced state of deterioration
	Surges or electrical transients	Breakdown of coil insulation	Loss of electrical and mechanical properties	Open circuited coil, failure of component in deenergized state	
Contaminants and/or moisture (in housing)	Temperature	Housing material degradation	Corrosion and/or rust	Loss of structural integrity	Detectable by inspection
Contaminants (in various mechanisms)	Degraded lubricant	High friction between moving parts	Wear of mechanism	Binding of mechanism	Detectable by inspection**
		Lubricant hardening	Stiffening or freezing of joints	Binding of mechanism	Detectable by inspection
Contaminants (on insulators)	Moisture	Surface current tracking on arc-chute insulating material	Decreasing surface resistance by dry banding damage	Loss of insulating properties, flashover	
Contaminants (on contact surfaces)	High current	Degradation of electrical components	Pitting or corrosion of contact surfaces	Arcing, contact welding	

* Energization at normal design voltage levels is not significant; however, it can cause problems when combined with other stressors.

** Detection by inspection not generally possible for mechanisms located within MCCBs.

eventually crack (i.e., lose its mechanical properties). Cracking of the insulation allows reduction or even complete loss of the insulator's electrical properties (especially in the presence of moisture), leading to the potential for flashover to ground or between phases. The temperature rise from ohmic heating of the conductor will accelerate the deterioration. MCC insulators are designed to withstand normal ambient and normal loadings for long durations (i.e., thermally induced degradation will occur very slowly). However, elevated ambient temperatures or excessive ohmic heating may cause early failure. The excessive ohmic heating that accompanies high resistivity connections can lead to more rapid insulation deterioration such that rather rapid insulation failure and flashover, and possibly burning, could occur. High resistivity connections could develop for each of these components because of (1) improper connection of bus bars and the bus joint, (2) poor mating of the main contacts, and (3) poor mating of the primary disconnects. High resistance connections have been noted in MCCs, and the potential for failure of the insulating components as a result of a loss of electrical and mechanical properties indicates that this aging mechanism is significant.

Loss of Surface Insulating Properties

In MCCs, voltage and humidity can affect energized insulation that is dirty or deteriorated and cause surface tracking paths on the insulator between phase and ground and adjacent phases. Dry tracking paths generally have high enough insulation values to prevent immediate flashover. However, moisture in the tracking path will allow larger leakage currents to flow. The leakage current flow will cause the moisture in the tracking path to evaporate because of ohmic heating. In addition, the leakage current will tend to remain constant such that the current density in the tracking path increases as moisture evaporates. Near the point where there is no longer moisture to conduct the current, localized burning of the insulation can occur. The process is called "dry banding" and causes an incremental amount of damage each time it occurs. Left uncontrolled, arc tracking and dry banding will eventually lead to a conductive track and insulation failure. In addition, heavy accumulations of dirt and other airborne contaminants could cause a conduction path to accumulate on the insulation that could allow breakdown between phases or phase to ground especially when condensation occurs. It should be noted that this discussion relates to standoff insulators where surface insulation properties are important.

Loss of Volumetric Insulating Properties

Another aging mechanism, loss of volumetric insulating properties, can result from the simultaneous exposure of thermally deteriorated insulation to temperature, voltage, humidity, dirt, and contaminants. Cracking produced by thermal stress can provide a leakage current path through the thickness of the insulation. In addition, humidity, dirt, and contaminants can reduce the surface resistance of the insulation such that the leakage current also travels across the surface of the insulation. This loss of both volumetric and surface insulating properties allows leakage current to flow through the thickness of the insulation as well as across its surface such that flashover to ground or between phases could occur.

A review of industry-wide operating experience indicates that a loss of volumetric and surface insulating properties has occurred during plant operation, and has caused insulation flashover. IE Circular 77-03, "Fire Inside a Motor Control Center,"[4.2] documents an MCC fire caused by a high resistance connection between the vertical bus and stab connector assembly.

The heating produced by the high resistance connection resulted in a breakdown of the insulation system.

The existence of surface current tracking and loss of volumetric and surface insulating properties has been documented. Because of the catastrophic nature of the resulting failure, both surface current tracking and loss of volumetric insulating properties are considered to be significant aging mechanisms.

High Resistance Electrical Connections

High resistance electrical connections can affect buswork (including the ground bus) and chassis ground connections. High resistance is caused by either poor mating surface contact (caused by a loose connection or fastener, foreign material, or corrosion/oxidation of the mating surface itself), or sharp bends/current flow restrictions near crimps or terminations. As discussed in IE Circular 77-03 above, high resistance electrical connections may result in excessive heating (and damage to other components) and potentially fire.

Loosening/Loss of Fasteners

Over-torquing of fasteners may result in elongation and thread damage, which may then lead to premature failure or loosening when coupled with mechanical stress and/or vibration. Reference 4.3 indicates that erroneous torque values may result in an elevated rate of fastener failure. Similarly, fasteners subject to various external stresses (such as non-seismic vibration) may loosen with time and eventually be lost. Over-torquing and loss of fasteners, while not a direct aging mechanism, could cause loss of structural integrity or affect electrical connections.

[4.4, 4.5, 4.6]

4.2.1.2 Molded-Case Circuit Breakers

The aging mechanisms associated with MCCBs are:

- contact surface degradation
- fatigue
- component wear
- loose or high resistance electrical connections or terminations
- thermal trip setpoint variations
- deterioration of lubricants
- current limiting fuse failure
- surface current tracking/loss of insulating properties
- thermally induced degradation

MCCBs generally require little attention and are expected to perform under fault conditions. Industry-wide operating experience indicates, however, that MCCBs are susceptible to various forms of age-related degradation. If not checked through periodic testing and preventive maintenance, these degradations can lead to breaker failure and the resulting compromise of required functions.

Contact Surface Degradation

The first aging mechanism associated with the MCCB is contact surface deterioration. Contact deterioration can occur with fault current interruption. The high temperatures that accompany fault currents may cause the contact material to vaporize, thereby inducing a loss of contact surface material and other undesirable effects such as pitting. Loss of contact material will also degrade the ability of the contacts to interrupt fault current. Degradation of contact surfaces with each electrical cycle could cause the contacts to burn or weld together such that MCCB function would be impeded.

Fatigue

The third aging mechanism for MCCBs is fatigue; fatigue may occur in a variety of MCCB components, including the operating mechanism, contacts, and molded breaker housing. Fatigue may be evidenced by the progressive cracking and ultimate failure of the component affected, and is generally the result of repetitive or cyclic mechanical stress placed on the component. Metallic components that are repeatedly stressed (such as the breaker contact assemblies and operating mechanism parts) are most likely to suffer from fatigue failure. Other related non-metallic subcomponents, such as the molded breaker housing, may also be exposed to cyclic stress (i.e., the case may act as a pivotal support for other breaker subcomponents and accordingly crack after repeated breaker operation). In general, MCCB components potentially at risk for fatigue failure have been designed to account for this phenomenon; hence, instances of fatigue failure in MCCBs are rare.

Wear of Internal Components

As with other mechanical components, molded-case breakers are subject to wear of their internal components. This wear is generally the product of inadequate or degraded lubrication or normal component wear caused by repeated cyclic operation. Mechanical wearout of breaker components may also be accelerated by contaminants (from other degraded material or from external sources) causing increased friction between moving components (contaminants are discussed in more detail in following paragraphs). Breaker subsystems such as the operating and trip mechanisms are subject to wear, and may affect the breaker's ability to fulfill its required function (manual close or trip on demand). For this reason, wear of the breaker internal mechanical components is considered a significant aging mechanism.

Loose or High Resistance Electrical Connections or Terminations

As with other electrical devices, loose connections and/or terminations associated with the MCCB can produce high resistances that, in turn, may generate significant amounts of heat (because of ohmic heating as described above). Operation of the breaker and other MCC components, as well as non-seismic vibration produced externally to the MCC, may cause breaker, bus, and load connections and terminations to loosen. Oxidization or contamination of contact surfaces (such as terminal lugs) may occur over time as well. Sharp bends in wiring occurring near terminations associated with the breaker may also loosen or deform the termination crimp so that the resistance of the connection is increased. Loose and/or broken wires may induce a variety of effects ranging from loss of continuity to arcing and fire within the MCC; hence, because of its large potential impact on MCC functionality, loosening of wiring connections and terminations is considered a significant aging mechanism.

Thermal Trip Setpoint Variations

Another degradation mechanism associated with bimetallic, thermally actuated molded-case breakers is variation in the thermal trip characteristic caused by exposure to fault currents. During fault conditions, heating of the trip device induces annealing effects in the trip device's bimetallic strip, changing its material characteristics. This change in material properties includes variation in the degree of strip deflection proportional to the current flowing through the strip. In general, the circuit breaker will trip at progressively lower current levels, potentially causing nuisance tripping during operation.

Deterioration of Lubricants

Deterioration of lubricants, which could occur because of contamination, aging, evaporation, or separation resulting from time and exposure to ambient temperature, could increase the amount of friction in the operating and trip mechanisms and cause binding. Additionally, mechanical cycling of MCCBs can cause the displacement of lubricants between moving parts; this displacement results in friction, which leads to wear and binding. Binding in the operating and trip mechanisms can slow or completely prevent operation because of an increase in the amount of force required to move the mechanism. If the contacts open too slowly, they can be damaged by the energy of the resulting sustained arc. If the contacts fail to open or only partially open (and current is not interrupted), complete failure of the circuit breaker caused by phase-to-phase or phase-to-ground flashover of the breaker insulation system could eventually occur.

As stated previously, a lack of periodic cycling of an MCCB can produce deleterious effects on the breaker's ability to operate. Lubricant hardening, separation, and displacement can cause increased resistance for internal moving parts. Feedback reports from several commercial nuclear plant operators have indicated that a substantial percentage of MCCB failures were attributable to a lack of cycling over long periods of time.

Current-Limiting Fuse Failure

Those MCCBs with current-limiting fuses installed may also experience fuse failure, thereby affecting the operation of the breaker. These fuses degrade slowly over time until eventually the current-carrying capability of the fuse is reached during normal/transient load operation, resulting in failure.

Surface Current Tracking and Loss of Insulating Properties

Breaker arc-chute insulation is especially susceptible to surface current tracking, as it may accumulate additional deposits from the vaporization of arcing contact material during current interruption. Surface current tracking and loss of volumetric/surface insulating properties are discussed in Sections 4.1 and 4.2.1.1 above.

Contaminants such as dust and dirt (which can lead to surface tracking) are not generally problematic in MCCBs. This is partly because MCCBs are encased in a sealed housing that protects the breaker internals against the outside environment. In addition, MCCs are not usually located in outdoor areas; hence, the level of contaminants present in the breaker's atmosphere is accordingly low. There is, however, a possibility of contamination of dust and dirt through MCCBs that may have vented arc-chutes. Also, dust or other contaminants may invade the breaker case during storage or shipping (prior to installation). The greatest possibility of dust and dirt contamination would be in extreme contamination conditions such as uncontrolled painting, sandblasting, or grinding in the vicinity of the MCC. The MCC housing itself may provide some degree of protection against these conditions.

Thermally Induced Degradation

Thermally induced degradation (caused by fault currents and continuous load currents) is also present in MCCBs. Fault currents can produce high temperatures and currents that can rapidly damage contacts, arc-chute surfaces, and other organic materials inside the breaker. Excessive temperatures can also result from continuous load currents coupled with poor contact mating. Poor mating of the contacts increases the resistance at the point of contact, thereby inducing additional heat production caused by ohmic heating. This may also be aggravated in those applications with relatively high ambient temperatures external to the breaker.

NRC Information Notice 92-03, "Remote Trip Function Failures in General Electric F-frame Molded-Case Circuit Breakers,"[4.7] discusses a problem with GE MCCBs UVRs and shunt trip devices that may prevent these internal accessory remote trip devices from functioning properly under conditions that produce sustained high internal temperatures in MCCBs. GE reported that the failures were caused by assembly and operational variations resulting from tolerances in mounting accessory devices in the MCCBs, tolerance in the adjustment of the ambient compensating bimetal, and sustained high temperatures in the MCCBs. The cause of the high internal temperature could be traced to a continuous high current load (greater than 50% of the rated load for more than two hours) coupled with a high ambient temperature or secondary heat source.

[4.4, 4.7, 4.8, 4.9, 4.10, 4.11]

4.2.1.3 Magnetic Contactors/Starters

The aging mechanisms associated with magnetic contactors and starters are:

- insulation deterioration
- prolonged energization/organic component breakdown
- cyclic fatigue
- wear of contactor and starter subcomponents
- contact degradation

Insulation Deterioration

During contactor/starter operation, the heat generated in the coil during energization (and by other MCC components) could cause insulation deterioration of the coil itself. As the period of energization increases, the insulation deterioration could increase proportionately and lead to turn-to-turn shorts and localized burning (because of the high local current and temperature at the site of the short). The increased temperature at the site of the short could also result in increased conductor resistance and thus increased ohmic heating of the site. The coil insulation would deteriorate further and could eventually fail and cause a short circuit of the coil to ground or possibly even an open circuit condition caused by conductor failure. Because degradation could cause failure of the contactor/starter that may preclude equipment operation, this aging mechanism is considered to be significant for these components.

Prolonged Energization/Organic Component Breakdown

Prolonged continuous energization of the contactor coil could shorten coil life and lead to coil burnout. Coil deterioration could result in excessive temperatures that cause organic compounds that encapsulate the contactor coil to degrade and possibly become semi-fluid. These semi-fluid compounds could then flow into the surrounding mechanisms and result in binding. Contactor coil failure and binding of the moving parts would be reflected as sluggish operation, failure to close, or failure to open.

Industry operating experience indicates that failure caused by prolonged, continuous energization of magnetic contactors has occurred. NRC Information Notice 91-45, "Possible Malfunction of Westinghouse ARD, BFD, and NBFD Relays, and A200 DC and DPC 250 Magnetic Contactors,"[4.12] discusses the potential for certain Westinghouse-supplied relays and magnetic contactors to fail because of age-related degradation. The failures were attributed to an epoxy compound becoming semi-fluid when the coils were energized for extended periods of time. The epoxy that encapsulates the coil was softened because of the heat of energization and flowed into the return string, causing binding. The failures were widespread throughout the nuclear industry. The manufacturer recommended inspecting all the relays and magnetic contactors that are normally energized, and testing them for epoxy softening after a period of at least two hours of energization.

Cyclic Fatigue

Depending on the duty cycle of the contactor load, fatigue may or may not be an aging problem. Cyclic fatigue can occur in magnetic contactors if subjected to extremely high cycle operation. During opening and closing cycles of the contactor, mechanical stresses are placed on various portions of the contactor assembly because of the applied force of the coil on the armature. In addition, magnetic contactors are ac devices that produce a characteristic ac hum (resulting from the alternating magnetic and electric fields), thereby causing vibration. Long-term exposure to vibration could cause wear and misalignment of contactor components, including the contact surfaces and the contactor armature. Wear of the contact surfaces, as previously described, can lead to increased heat generation because of higher resistivity. Wear of the contact armature may create contact misalignment as well as binding of the armature, thereby preventing full contact mating and arcing. Therefore, cyclic fatigue is considered a significant aging mechanism for magnetic contactors and starters.

Wear of Starter/Contactor Subcomponents

Wear, a fourth aging mechanism fcr the starter and contactor, can result from high friction between moving parts and could cause the contactor armature to bind. High friction between moving parts can be caused by deterioration of lubricants (if used), dirt or other contamination, and misalignment/loss of tolerances of the components. Binding of the contactor assembly components could impede operation of the moving components such that the closing operation might be inhibited and the connected load would fail to start. Similarly, binding of the contactor armature could prevent the contacts from disengaging fully, thus potentially causing arcing across the contact surfaces and loss of control of the load.

In addition, binding in the contactor mechanism can result in excessive heat generation in the coil. The impedance of a magnetic circuit having a substantial air gap (such as in a contactor assembly) is much lower than the impedance of the same magnetic circuit having little or no air gap. The current drawn by the coil of an ac magnet is therefore much greater at open gap than at closed gap. Because closing time is short, ac coils are designed to withstand continuous energization only under closed conditions. Hence, ac coils may soon overheat if the mechanism is blocked open (such that the gap is not closed) or the voltage is too low to cause contactor operation. Direct-current (dc) coils are not generally subject to these conditions described above because the coil currents do not vary with the gap. In certain applications, dc coils are momentarily energized at much higher than rated currents; however, this high momentary current at closing is not damaging unless it is sustained over long periods of time.

Contact Surface Degradation

Contaminants such as dust, dirt, and foreign material within a contactor can lead to coil burnout, pitting of contact surfaces, and breakdown of adhesives and lubricants. Contaminants on contact surfaces prevent the contact from closing and lead to an insufficient contact area that could cause increased pitting and damage to the contact surfaces. Contaminants may also cause wear and binding of various contactor mechanisms such as the interlock and auxiliary contacts. It should be noted however that in most contactor applications, levels of dirt and other contaminants are relatively low.

[4.4, 4.9-4.11, 4.13, 4.14]

4.2.1.4 Thermal Overload Relays

As previously discussed, two types of thermal overload elements are primarily used in MCC applications: eutectic and bimetallic. In the eutectic device, metal with a known melting point is used to control the motion of a ratchet that allows operation of the relay. In the bimetallic device, varying thermal expansion coefficients of adjacent materials are used to "bend" a bimetallic element sufficiently to actuate the mechanism at a predetermined current. Potential aging mechanisms for these overload devices include:

- degradation of heater or bimetallic elements
- binding of mechanical components
- contact surface degradation
- thermal degradation of organic materials
- loose or high resistance electrical connections or terminations

Degradation of Heater or Bimetallic Elements

In eutectic devices, the actuation point of the relay is determined by the physical properties (i.e., melting point) of the eutectic alloy. As these properties do not change appreciably over the life of the device, little variation in the setpoint is expected. However, deterioration of connections or device contacts is possible.

In the bimetallic device, actuation is controlled by the amount of heat applied to the bimetallic strip by the heater element. Hence, variations in the current flowing through the heater will result in variations in the setpoint of the device. These variations may be caused by changes in the characteristics of the heater element itself. Additionally, changes in the bimetallic strips over time could affect the performance (i.e., trip point) of the relay.

Binding of Mechanical Components

Binding of the contact mechanism may occur because of mechanical interference, dirt, or friction. Foreign materials introduced into the mechanism can prevent the contacts from actuating properly, or require additional force actuation. Other contactor components may also interfere with the contact armature (caused by movement, thermal variation, or other loss of tolerance) and similarly prevent proper operation of the contacts. Atmospheric contaminants deposited on contact or armature surfaces may also result in "sticking" of the mechanism.

Contact Surface Degradation

Degradation of contacts surface in thermal overload relays is analogous to that described for Starters/Contactors above. See Section 4.2.1.3.

Thermal Degradation of Organic Materials

Another degradation mechanism associated with bimetallic overload relays is aging of the heater element support material (generally a phenolic) because of elevated temperatures caused by the heaters. Current is continually passed through the heater elements, which generate heat in proportion to the current. Constant exposure of the heater support structure to the temperature generated by the heaters will embrittle and age the material such that its mechanical properties will degrade over time. Embrittlement, cracking, and ultimate failure of the support block may eventually affect the physical arrangement of the heaters with respect to the overload element, resulting in possible failure of the overload relay to perform its required function. Although the materials are designed to withstand normal operating conditions, long-term exposure may lead to deterioration.

Loose or High Resistance Electrical Connections or Terminations

As with other electrical devices within the MCC, thermal overload relays may also be subject to loose and/or high resistance electrical connections that could change operational characteristics and cause additional localized heating. This aging mechanism is described in further detail in preceding sections.

[4.4, 4.11]

4.2.1.5 Miscellaneous Relays

The aging mechanisms associated with relays are:

- prolonged energization and thermal breakdown of organic materials
- contact surface degradation
- wear of mechanical parts
- loose or high resistance electrical connections or terminations

These age-degradation mechanisms result from thermal, mechanical, electrical, and environmental stresses. These stressors experienced over time can create changes in the response time, coil, and contact characteristics.

Prolonged Energization and Thermal Breakdown of Organic Materials

High temperatures caused by continuous long-term energization of the relay coil may result in the deterioration of coil insulation and other nonmetallic materials; for additional details, refer to the discussion of prolonged energization contained in Section 4.2.1.3 above.

Coil failure caused by overheating and continuous energization of the relay coil has been noted. (Note: Not all of the documents cited below necessarily refer to relay types used in MCCs; rather some of these documents are included as evidence of the existence of the relay aging mechanisms described above, and may or may not be applicable to relays used in specific MCC applications.)

IE Bulletin 76-05, "Relay Failures - Westinghouse BFD Relays,"[4.15] cites two events related to BFD relays. One relay had an open circuit failure of the coil, whereas the other relay exhibited excessive opening times. It was determined that both relay failures were caused by overheating of the relay coils. Overheating may result in coil insulation breakdown and melting of the coil solder joints, leading to open circuit failure. Overheating may also result in deformation of the Nylon coil sleeve in which the plunger travels, adversely affecting the relay opening time.

IE Bulletin 79-25, "Failures of Westinghouse BFD Relays in Safety-Related Systems,"[4.16] reports the case of a relay found to be stuck in the energized positions with the coil de-energized. The armature was sticking to the armature stop post. The condition was found to be a result of the heat generated by normally energized coils, which caused softening and a resultant flow of the epoxy adhesive (used to attach the magnetic anti-stick disc to the top of the armature stop post), thereby bonding the armature to the stop post. Replacement of the relays was requested.

IE Information Notice 82-02, "Westinghouse NBFD Relay Failures in Reactor Protection Systems at Certain Nuclear Power Plants,"[4.17] reveals that at high temperature conditions the relay coils of BFD and NBFD relays could fail (open circuit) because of the inductive voltage spike generated by the deenergization of the relay coil.

IE Bulletin 78-06. "Defective Cutler-Hammer Type M Relays with DC Coils,"[4.18] reports four continuously energized relays that failed because of loss of arc gap in the coil clearing contact. The loss of arc gap was caused by an abnormal amount of heat-induced shrinkage of the molded magnet carriers; the magnet carrier shrinks to a point where the arc gap in the coil clearing pole becomes too small to break the inrush current of the pickup coil winding, causing the coil to overheat and burn out. Coil overheating may also result in the relay being stuck in the energized position, preventing it from dropping out when the power is removed from the coil. Only certain dc coils are affected; ac coils do not use the coil clearing contact feature, and not all dc coils are so equipped.

IE Bulletin 84-02, "Failures of General Electric Type HFA Relays in Use in Class 1E Safety Systems,"[4.19] and IE Information Notice 84-20, "Service Life of Relays in Safety-Related Systems,"[4.20] discuss the abnormally high failure rate of normally energized GE type HFA relays. The failures, which consisted of the deterioration of the coil wire insulation, were caused by shorted coil turns that increased coil temperatures. The high coil temperatures caused the insulating material to vaporize and the coil spool to melt. These materials then deposited on cooler surfaces of the relay, causing armature damage and/or failure of the circuit to make contact. According to the manufacturer, the ac rated HFA relays manufactured with standard Class A insulation (Nylon or Lexan coil spools and standard temperature wire) that are continuously energized can fail in approximately 10 to 12 years. Replacement with a new model line that uses a high-temperature coil spool and wire employing vacuum-impregnated insulation is recommended.

NRC Information Notice 88-88, "Degradation of Westinghouse ARD Relays,"[4.21] addresses deficiencies in 125-Vdc ARD relays that were found to have increased drag between the solenoid's coil spool and the armature. The increased drag was caused by the deterioration of the coil potting compound. The granules from the deteriorated potting lodged between the solenoid's coil spool and the armature, causing sluggish operation of the relay. This compound contains a sand-based material that has since been revealed to break down with age.

NRC Information Notice 91-45, "Possible Malfunction of Westinghouse ARD, BFD, and NBFD Relays, and A200 DC and DPC 250 Magnetic Contactors,"[4.12] discusses the potential for certain Westinghouse-supplied relays and magnetic contactors to fail because of age-related degradation. The failures were attributed to an epoxy compound becoming semi-fluid when the coils were energized for extended periods of time. The epoxy that encapsulates the coil was softened because of the heat of energization and flowed into the return spring, causing binding.

Contact Surface Degradation

Contact surface deterioration in relays are analogous to that experienced in starter/contactor assemblies; see Section 4.2.1.3 above for additional discussion of these topics.

Wear of Mechanical Parts

Wear and other stressors can lead to setpoint drift (for protective or timing relays), mechanical fatigue, surface burning caused by arcing, and insulation deterioration during normal and abnormal operation of MCC relays. Wear caused by normal relay operation reduces mechanical tolerances, thereby creating misalignment, loose connections, and increased resistances, which can result in arcing, heat propagation, contact degradation, and eventual breakdown of coil insulation. Wear caused by cyclic loading (such as external vibration) can result in jamming or binding of the moving parts because of friction. Friction may also be a result of the presence of dust and dirt in the relay's mechanisms. Friction and wear will prevent full travel of the armature, keeping the relay contacts from properly making or opening.

Vibration wear can be induced internal to the relay; excessive vibration of this type can cause notching or misalignment of the mechanism parts such that the tolerances between the armature and magnet assembly would be exceeded; this could potentially keep the contact assembly from seating properly. This, in turn, could lead to increased contact resistances and arcing, and possibly accelerate other aging mechanisms.

IE Circular 79-20, "Failure of GTE Sylvania Relay, Type PM Bulletin 7305, Catalog 5U12-11-AC with a 120-Vac Coil,"[4.22] discusses relay failure caused by notching in the armature operating rod. The notch occurs where the rod vibrates (because of coil hum) against the magnet assembly; eventually the notch is of sufficient size that it impedes the operation of the relay. Many relay failures have been attributed to this phenomenon. This circular recommends inspection of the armature operating rods for evidence of notching.

Loose or High Resistance Electrical Connections or Terminations

Miscellaneous relays may also be subject to loose and/or high resistance electrical connections that could change operational characteristics and cause additional localized heating. This aging mechanism is described in further detail in preceding sections.

Other Potentially Significant Aging Mechanisms for Miscellaneous Relays

The following aging mechanisms may be significant under certain operational and environmental conditions.

Degradation Resulting From Electrical Stresses

Electrical stresses are inherent in MCC auxiliary relays because of nominal voltages during normal operations. Normal operational voltages do not significantly stress a relay; however, coupled with other stresses or previous stresses, degradation of the relay components may occur. Inductive voltage surges result from current interruptions and can stress the relay coil. The inductive surge may cause coil dielectric breakdown at the weak points in the insulation, which can rapidly lead to insulation failure.

Degradation Resulting From External Contaminants

Although relays are enclosed within the MCC enclosure, thereby diminishing environmental stresses and exposure to contaminants and harsh environments, foreign materials still present a potential aging hazard. In certain relay designs, environmental conditions such as humidity, oxidation, dust, dirt, and chemical contaminants provide stresses that can lead to failure. Condensation across the electrical paths may reduce surface insulating characteristics. Corrosion results from condensation and can lead to binding of the relay. As previously mentioned, dust and dirt may cause frictional problems and contribute to wear. Chemical contaminants may cause premature breakdown of the relay's organic materials and contribute to contact oxidation, causing binding, sticking, or failure.

[4.4, 4.11]

4.2.1.6 Control Transformers

The aging mechanisms for control transformers are:

- winding insulation degradation
- winding conductor failure
- loose or high resistance electrical connections or terminations

Winding Insulation Degradation

Winding insulation degradation is caused by elevated insulation temperature (caused by ohmic heating and breaker internal ambient conditions) and electrical cycling. Degraded winding insulation can produce shorted transformer windings (turn to turn), resulting in faulty voltage/ current transformation or even open circuit conditions.

Winding Conductor Failure

Primary or secondary winding conductor failure can result from continuous use for extended periods (especially if accompanied by localized insulation failure or burning) or from excessive current drawn through the winding from attached control power loads. Generally, control power transformers are protected from excessive current conditions via installed control power fuses; hence, failure of either winding caused by excessive current is considered non-significant.

Loose/High Resistance Electrical Connections or Terminations

Loose or high resistance electrical connections or terminations could occur in a fashion similar to that described in the preceding discussion of other components; thus, this aging mechanism is also considered significant for control transformers.

4.2.1.7 Terminal Blocks

The significant aging mechanisms for terminal blocks are:

- loose or high resistance electrical connections or terminations
- degradation of organic materials
- degradation of terminal block hardware
- loss of surface and volumetric insulating properties

These mechanisms can result in localized high temperatures, electrical faults, open circuits, flashover of insulation, and loss of terminal block material integrity.

Loose or High Resistance Electrical Connections or Terminations

As with other electrical devices, loose connections and/or terminations associated with terminal blocks can produce high resistances that, in turn, may generate significant amounts of heat (caused by ohmic heating as described above). Operation of MCC components, as well as non-seismic vibration produced externally to the MCC, may cause MCC connections and terminations to loosen. Oxidization or contamination of contact surfaces (such as terminal lugs) may also occur over time.

Degradation of Organic Materials

Terminal blocks may also degrade because of ohmic and ambient heating; these blocks are generally constructed of organic material, such as phenolic, that may lose its mechanical integrity (i.e., it may crack or embrittle and therefore lose its support and insulating capabilities). In terms of mounting arrangement, some terminal blocks are fastened into place using some form of organic glue or bonding agent, which may also degrade with time because of ohmic and ambient heating, humidity, and vibration occurring in the vicinity of the terminal block. This degradation may result in the loosening or falling of the terminal block into other MCC components, potentially causing mechanical interference, short circuits, and loss of equipment function.

Degradation of Terminal Block Hardware

Terminal block hardware degrades primarily as a result of stresses produced during normal use (such as maintenance or testing). Improper maintenance techniques (such as overtightening of hardware fasteners) exacerbates this degradation.

A review of industry-wide operating experience produced one document related to terminal blocks. IE Information Notice 80-08, "The States Company Sliding Link Electrical Terminal Block,"[4.23] discusses defects with States sliding-link terminal blocks relating to cracking between the threaded screwhole and the side of the U-shaped link. This crack widens when the screw is tightened, resulting in a poor or intermittent electrical connection. This defective mechanical connection can ultimately result in an electrical circuit malfunction.

In general, if connections are properly made, maintenance and testing properly performed, and the terminal blocks are used within their ratings, deterioration of the block and its hardware should be negligible.

Loss of Surface and Volumetric Insulating Properties

Terminal block organic insulating materials may be susceptible to the loss of their surface and volumetric insulating properties in a fashion similar to that of other MCC components (see preceding discussions).

4.2.1.8 Control Wiring

The aging mechanisms for MCC control wiring are:

- insulation degradation
- conductor degradation
- loose or high resistance electrical connections or terminations

Insulation Degradation

Insulation degradation can occur with exposure to elevated ambient temperature, ohmic heating of the conductor, and excessive ohmic heating that accompanies high resistivity connections. Exposure to ambient temperature can cause the bond structure of the insulation to change such that the insulation will harden, embrittle, and eventually crack (i.e., lose its mechanical properties), resulting in a loss of insulating capability. Ohmic heating of the conductor will intensify the deterioration caused by ambient temperature such that it may gradually lead to insulation failure. The excessive ohmic heating that accompanies high resistivity connections could lead to rapid localized insulation deterioration. Organic materials may also interact with contaminants and other environmental influences, thereby breaking down the structure of the material. In general, deterioration of the insulating properties of wiring occurs very slowly.

A review of industry-wide operating experience indicates that a loss of insulation integrity has occurred during normal operation and caused flashover of wire insulation. This was reported in NRC Information Notice 91-20, "Electrical Wire Insulation Degradation Caused Failure in a Safety-Related Motor Control Center,"[4.24] which discusses the foreign hardened coating on one of the contactors, which was traced to the dielectric polyvinyl chloride machine tool wires that were producing a green liquescent substance. This substance was caused by the combination of an electrochemical reaction, moisture from the environment, interaction between the corrosion products formed on the surface of the copper wire, and the chlorine leaching from the wire's insulation (see Section 3.6.1).

Conductor Degradation

Conductor degradation may result from bending, pulling, or crimping of the conductor or from localized heating (either from an external heat source or ohmic heating within the wire).

Loose or High Resistance Electrical Connections or Terminations

Loose or high resistance connections or terminations may occur from bending or pulling on the wiring (i.e., during maintenance), vibration of components, inadequate torquing of fasteners, or oxidation/corrosion/contamination of termination contact surfaces. Localized ohmic heating of connections may also exacerbate the problem.

[4.25, 4.26]

4.2.1.9 Fuse Holders

The significant aging mechanisms for fuse holders include:

- cyclic fatigue
- high resistance contact surfaces
- loose or high resistance electrical connections or terminations

A review of industry data indicates that failures of certain types of fuses have been recorded on several occasions (see Information Notice 87-62 in Section 3.6.1.9 of this guideline); however, no failures of fuse holders were identified in the NRC documentation.

Cyclic Fatigue

Cyclic fatigue of the fuse holder is primarily associated with the installation or removal of fuse elements; usually some sort of frictional arrangement is employed to keep the fuse secure and properly connected (typically a metal spring-clip or spring-loaded housing). Fuse clip fatigue from use is not expected unless an unusual condition such as extreme overheating or repetitive fuse failures occurs.

High Resistance Contact Surfaces

High resistance contact surfaces may result from corrosion, oxidation, or contamination of the surfaces in contact with the fuse element itself. This condition may result in a loss of continuity or increased localized heating.

Loose or High Resistance Electrical Connections or Terminations

Loose connections and terminations are discussed in preceding subsections of this guideline.

4.2.2 Non-significant Aging Mechanisms

4.2.2.1 Motor Control Center Metal Housing

The potential failure mode for the MCC housing structure is a loss of structural integrity, i.e., a loss of structural alignment or a loss of seismic withstand capability. Loss of structural integrity could result from one of two aging mechanisms:

- material fatigue and degradation
- loss of components

Material Fatigue and Degradation

Material fatigue, resulting from mechanical stress or excessive vibration, could cause housing welds to crack or weaken. Material degradation, resulting from exposure to contaminants and moisture, could cause the structural members and fasteners to rust, pit, and corrode, thereby affecting the structural integrity of the housing.

Loss of structural integrity is a concern for the MCC housing because the housing protects and supports the internal components. However, industry-wide operating experience with the metal housing systems (see Section 3.6) indicates that they have performed without failure up to the present time. In addition, Reference 4.1 states that the metal housing system does not have a tendency to age significantly with time. Therefore, unless the motor control center is located in high moisture/corrosive environments (such as being outside in salty ocean air), material deterioration of the metal housing is not a significant aging mechanism. In general, the MCCs under consideration in this study are located indoors in non-corrosive, low-vibration environments; moisture or contaminants at the levels necessary to induce degradation of the structural integrity of the housing would likely be detected in other equipment or components first. In those cases where the equipment is located in such a corrosive or high-vibration environment, aging of the housing may be significant, and must be addressed by appropriate maintenance practices.

Loss of Components

Although loss of components is not directly an aging mechanism, inadvertent loss of fasteners could cause a loss of anchoring and structural strength. Loss of components could occur because of poor maintenance practices. Maintenance of the housing structure may involve removal of housing enclosure parts for cleaning and visual inspection. When the housing enclosure parts are replaced, fasteners or hardware may be inadvertently left out. If a fastener or piece of hardware is left out each time the equipment is serviced, the number of missing fasteners will increase with time and could eventually result in a loss of structural integrity. However, review of the industry-wide operating experience indicates no occurrences of loss of fasteners or other housing components resulting in a loss of MCC housing structural integrity. Therefore, this aging mechanism is not considered significant.

4.2.2.2 Switches

The applicable aging mechanisms for switches are:

- high resistance contact surfaces
- loose or out-of-adjustment contacts
- loose or high resistance electrical connections

However, because these devices do not affect MCC functionality, these aging mechanism are deemed insignificant.

4.3 References

4.1 NUREG/CR-4715, BNL-NUREG-52017, "An Aging Assessment of Relays and Circuit Breakers and System Interactions," prepared by Franklin Research Center, June 1987.

4.2 IE Circular 77-03, "Fire Inside a Motor Control Center," February 28, 1977.

4.3 NRC Information Notice 88-11, "Potential Loss of MCC and/or Switchboard Function Due to Faulty Tie Bolts," April 7, 1988.

4.4 NUREG/CR-5053, BNL-NUREG-52188, "Operating Experience and Aging Assessment of Motor Control Centers," prepared by Brookhaven National Laboratory, July 1988.

4.5 General Electric Company, GEH-2514F, "General Electric Installation and Maintenance of 7700 Line Motor Control Center."

4.6 Bechtel Power Company, Instruction Manual Operation-Maintenance Instructions and Parts Catalog for AC Motor Control Center IC7700, GEK-73389, Volume 1, order number 10407-13-EM-018.

4.7 NRC Information Notice 92-03, "Remote Trip Function Failures in General Electric F-Frame Molded-Case Circuit Breakers," January 6, 1992.

4.8 G. Toman, "Evaluation of Failure to Trip of Reactor Trip Circuit Breakers on February 22 and 25, 1983, Salem Nuclear Generating Station Unit 1," Franklin Research Center, TER-C5506-413, February 25, 1984.

4.9 S. P. Carfagno and G. Erich Heberlein, Jr., "A Study of the Effect of Aging on the Operation of Switching Devices," IEEE paper F 80 259-2.

4.10 FRC Final Report F-C4590, "A Study of the Effect of Aging on the Operation of Switching Devices During Vibration at Frequencies in the Seismic Range," Franklin Research Center, October 1977.

4.11 Westinghouse Electric Corporation, Electrical Maintenance Hints - Volume 2, "Industrial Equipment Maintenance," 1984.

4.12 NRC Information Notice 91-45, "Possible Malfunction of Westinghouse ARD, BFD, and NBFD Relays, and A200 DC and DPC 250 Magnetic Contactors," July 5, 1991.

4.13 "Motor Starter Troubleshooting and Maintenance Guide for Westinghouse Controls," February 1981.

4.14 Westinghouse Instruction Leaflet 15-800-M 010/110/210-1B, "Type M D-C Magnetic Contactors Frames 010, 110 and 210 Single-Pole Magnet Closed," May 1950.

4.15 IE Bulletin 76-05, "Relay Failures — Westinghouse BFD Relays."

4.16 IE Bulletin 79-25, "Failures of Westinghouse BFD Relays in Safety-Related Systems," November 2, 1979.

4.17 IE Information Notice 82-02, "Westinghouse NBFD Relay Failures in Reactor Protection Systems at Certain Nuclear Power Plants," January 27, 1982.

4.18 IE Bulletin 78-06, "Defective Cutler-Hammer Type M Relays with DC Coils," May 31, 1978.

4.19 IE Bulletin 84-02, "Failures of General Electric Type HFA Relays in Use in Class 1E Safety Systems," March 12, 1984.

4.20 IE Information Notice 84-20, "Service Life of Relays in Safety-Related Systems," March 21, 1984.

4.21 NRC Information Notice 88-88, "Degradation of Westinghouse ARD Relays," November 16, 1988.

4.22 IE Circular 79-20, "Failure of GTE Sylvania Relay, Type PM Bulletin 7305, Catalog 5U12-11-AC with a 120-Vac Coil," September 24, 1979.

4.23 IE Information Notice 80-08, "The States Company Sliding Link Electrical Terminal Block," March 7, 1980.

4.24 NRC Information Notice 91-20, "Electrical Wire Insulation Degradation Caused Failure in a Safety-Related Motor Control Center," March 19, 1991.

4.25 IE Information Notice 82-03, "Environmental Tests of Electrical Terminal Blocks," March 4, 1982.

4.26 IE Information Notice 84-47, "Environmental Qualification Tests of Electrical Terminal Blocks," June 15, 1984.

5. EFFECTIVE MANAGEMENT OF AGING MECHANISMS

5.1 Listing of Generic Elements of an "Effective" Aging Management Program

Methodologies have been established by the U.S. Nuclear Regulatory Commission for determining if a plant program is effective in detecting and mitigating the effects of aging. These criteria are provided in 10 CFR Part 54.21[5.1], and state that an aging management program is effective if:

1. The program is documented, its implementing procedures are approved by onsite review committees, and it is implemented in accordance with plant administrative procedures, and

2. The program ensures identification and mitigation of age-related degradation unique to license renewal for systems and components important to license renewal, and

3. The program establishes specific acceptance criteria against which the need for corrective action is to be evaluated and requires timely corrective action to be taken when the acceptance criteria are not met.

Except for age-related degradations unique to license renewal, these methodology criteria will be applied to the maintenance and surveillance techniques and programs discussed in Sections 5.2 and 5.3 to determine if the current programs are effective in mitigating the aging of MCCs and their components (see Section 5.4). Further guidance on the specific methodology for performing maintenance on MCCBs can be found in Reference 5.2.

The programs described in this section are suggested, not required. The approach used is to present guidelines and give alternatives for plant personnel to use. Different combinations of programs and techniques can be used to create an effective program specific to each utility and plant site.

5.2 Common Maintenance and Surveillance Techniques and Programs Used, Including Refurbishment and Replacement

Maintenance and surveillance of MCCs is performed to ensure that the characteristics or attributes essential for operation are maintained. The following activities are commonly performed during maintenance and surveillance of MCCs.

- Visual inspection
- Measurement of component properties (such as electrical resistance, contact tolerances)
- Cleaning
- Adjustments
- Lubrication

- Operability checks and testing
- Component replacement.

In general, maintenance on MCCs is either preventive or corrective in nature. Preventive maintenance is conducted based on either a given periodicity (every refueling cycle, for example) or the actual condition of the installed components (see Section 5.3.2 below). Usually only a portion (for example, one-quarter to one-third) of the MCCs are examined during any given maintenance cycle. This results in a 6- to 8-year maintenance and inspection interval for most MCCs.* Some plants choose to maintain safety-related MCCs each refueling period. Most plants employ time-based maintenance schedules, primarily because of the simplicity of administering such schedules, as well as the lack of component degradation/failure information necessary to justify condition-based programs. In many cases, the preventive maintenance activities (especially of safety-related MCCs) coincide with the refueling outages, when MCC components can be removed from service with less effect on the safety and operations of the plant. Corrective maintenance occurs on an as-needed basis usually as a result of component failure; it is performed to repair an inservice failure. Simple troubleshooting and repair/replacement of the faulty component are dictated in most cases.

In addition to preventive maintenance, functional surveillance tests require safety-related MCC components to be verified periodically as being operable. When safety systems are exercised under the surveillance program, the associated MCC and control circuitry are also generally exercised, allowing verification of the functionality of the active MCC components.

To more comprehensively describe the maintenance and surveillance techniques commonly used to maintain MCCs, vendor and utility maintenance procedures were reviewed. The results of the review follow. Common maintenance and surveillance techniques are discussed for each component. Note that certain subsections and discussions apply to specific types of MCC components. For example, breaker thermal trip device discussions would not apply to magnetically actuated breakers, and bimetallic overload discussions would not apply to eutectic devices.

It should be noted that each of the maintenance and surveillance techniques described in the following sections is not necessarily applied to each device individually; in most cases the MCC cubicle or bucket was evaluated as a whole. Many of the techniques described, such as visual inspection and cleaning of wiring and connections, are performed on the MCC bucket as a whole rather than as discrete individual tasks; this helps reduce the maintenance burden associated with the equipment. In addition, in-depth testing or evaluation of individual MCC components may be conducted based on factors such as the type and operating demands of a specific application, prior component maintenance and failure history, and the results of other tests and procedures (such as functionality tests or visual inspections).

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* Maintenance intervals for safety-related and non-safety-related MCCs vary from plant to plant, yet generally appear to fall within the range of 4 to 10 years.

5.2.1 Motor Control Center Structural Components (Including Metal Housing, Bus Structure, Terminals, and Disconnects)

The common maintenance practices currently used to maintain the structural components are visual inspection, cleaning and vacuuming, lubrication, component/subcomponent replacement, and verification of the tightness of components. In general, these practices will be employed during each scheduled maintenance period (i.e., once per refueling cycle, on a rotating basis) or during corrective maintenance requiring entry into the MCC. The visual inspection that is performed controls one of the housing system's aging mechanisms: structural failure of the housing from material fatigue. Visual inspection for loose or broken parts, corrosion, rust, and cracked welds ensures the structural integrity of the housing system by identifying fatigue before it significantly weakens the metal housing members. Visual inspection, when combined with cleaning, painting, and occasional component replacement (such as restoration of lost fasteners), controls another aging mechanism for the metal housing system: material degradation. Material degradation is controlled by visual inspection (for paint damage, indications of corrosion or rusting, and obstruction of vents) and cleaning of the MCC structure and compartments. The final aging mechanism for the metal housing system, loss of fasteners, is controlled by verification of the tightness (or torque) of anchoring and housing fasteners and replacement of lost or loose fasteners. Verification of the tightness of components and replacement as required ensure that the metal housing system will remain securely fixed to the building structure and that the housing parts will remain tightly fastened to one another, ensuring structural integrity.[5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 5.10, 5.11]

The common maintenance practices currently used to maintain electrical connection bolt integrity at terminals and disconnects are checking the connections (cable connections, main and vertical bus joints, main bus supports) for proper tightness/torque; visual inspection for signs of overheating, damage and deterioration; and infrared thermography.

Visual inspection, cleaning of insulating surfaces, and insulation resistance testing control two internal bus system aging mechanisms: surface current tracking and loss of volumetric insulating properties of support insulators. Visual inspection of the bus insulators for tracking paths, evidence of overheating, surface contamination, surface irregularities, and discoloration allow identification of surface current tracking. Visual inspection also helps in the identification of cracking, chipping, fraying, or embrittlement of the wiring and terminals, thereby allowing identification of any loss of volumetric and surface insulating properties. Cleaning and vacuuming of the internal bus system components (wiring and cable troughs, terminals, MCCB externals, etc.) prevent the accumulation of dust, dirt, and contaminants that, particularly in the presence of moisture, could provide tracking paths to ground. Cleaning also helps to prevent the deterioration of volumetric insulating properties by removing contaminants that could cause chemical deterioration of the insulation. Insulation resistance testing provides a means of monitoring the significant deterioration of insulating capabilities.[5.2, 5.3, 5.6-5.9, 5.12, 5.13]

Power stabs are also checked for a light coating of non-oxidizing grease and for the mechanical and electrical integrity of the connections. Contamination or dirt present on the stabs (other than the lubricant) should be removed to ensure adequate contact. The contact surfaces are inspected for signs of corrosion and oxidation, which may result in high resistance connections that could overheat.

5.2.2 Molded-Case Circuit Breakers

The common maintenance practices currently used to maintain the MCCBs and their operating linkage are visual inspection, cleaning, operability checks and testing, component adjustments (verification of the tightness of connections and adjustment of the operating handle/linkage), and lubrication of the operating handle mechanism. Many of the aging mechanisms associated with MCCBs and associated equipment can be controlled or monitored by external means (e.g., wear/loss of adjustment of the external breaker operating handle, bimetallic annealing, high resistance connections, and fatigue cracking of external components); however, because most MCCBs are sealed, access to most internal subcomponents is extremely limited. The current maintenance practice used to maintain the operating mechanism and internal mechanical parts is periodic cycling; cleaning, visual inspections, and lubrication of internal components are used only in those instances where the internals of the breaker are accessible and designed for routine maintenance.

The gradual deterioration of lubricants and internal components is controlled through handle operation and breaker cycling. Periodic exercising of the breaker ensures that binding, excessive friction, or improper alignment of the operating mechanism does not exist and may help distribute the lubricants throughout the mechanical parts to limit drying or hardening. Operational tests may also help clean contact surfaces via their inherent wiping motion, thereby assisting in the control of their deterioration.

The aging mechanism of material embrittlement of the molded body is controlled by inspection for cracks, overheating, discoloration, and loose terminations or connections. This will help detect material embrittlement caused by thermal stresses and ensure the structural integrity of the MCCB frame. In general, embrittlement of the molded case is not a primary concern because of the characteristically slow aging of the phenolic materials of which the case is constructed.

Wear of the breaker operating handle and linkage is controlled by inspection of the mechanism for dirt, corrosion, or signs of lubricant deterioration; tolerances and adjustments are verified as well as the operability of the mechanism. Screws, springs, and retaining rings are verified tight and in their proper position.[5.11]

The maintenance operability tests that are currently used to maintain the circuit breaker trip devices are the insulation resistance, individual pole power circuit resistance, rated current hold-in, overload trip, instantaneous magnetic overcurrent trip, and shunt trip tests. Additionally, the operability of the auxiliary contacts of the breaker (if so equipped) will be verified via functional testing. Generally speaking, these tests are performed only during scheduled MCC/cubicle maintenance (i.e., once per refueling outage on a rotating basis), after replacement of the breaker, or when the performance of the breaker is suspect. Shunt and undervoltage trip devices are periodically tested where they are in use. These maintenance practices control the following aging mechanisms: deterioration of the latch mechanism, contact surfaces, and insulation; the loss of mechanical properties and breaker integrity; annealing of the bimetallic thermal trip element; and deterioration of lubricants. These tests are described below.

5.2.2.1 Insulation Resistance Test

The insulation resistance test assesses the quality of insulation between the poles of a circuit breaker and between its pole and ground. Low insulation resistance would indicate wet, contaminated, flawed, or cracked insulating material. Usually extreme environmental conditions (such as condensing moisture or heavy conducting dust) must be present to reduce the dielectric withstand ability of the insulating material. MCCBs are not usually exposed to these environments; therefore, low resistance is not a common failure mode in nuclear power plant MCCBs. In general, an acceptance criterion for the line-to-load reading with the breaker open, phase-to-phase, and phase-to-ground resistances would be greater than 2 megohm. Resistance values with less than 1 megohm are considered unsafe and require investigation. The line-to-load resistance with the breaker closed should be on the order of a few milliohms.[5.14]

In general, the insulation resistance test should be performed only when other tests are scheduled. If resistance measurements were not within the acceptance criteria, the circuit breaker would be replaced or the manufacturer would be consulted before restoring the circuit breaker to service.[5.2, 5.3-5.5, 5.12, 5.13, 5.14, 5.15, 5.16, 5.17, 5.18]

5.2.2.2 Individual Pole Resistance Test

Internal circuit breaker problems such as loose connections or damaged contact surfaces can be detected by the individual pole resistance test. Other names for this test are the millivolt drop test, contact resistance test, breaker resistance test, and watts-loss test. This test evaluates the electrical quality of the connections and contacts in a circuit breaker by measuring the millivolt drop across each pole. The test can determine contact resistance under operating conditions or while the contact is de-energized, depending on the desired results. High contact resistances are potentially indicative of contact damage; however, the test results can be easily affected by differences in test connections, types of equipment, and test personnel.[5.2, 5.3-5.5, 5.12, 5.14-5.18, 5.19, 5.20]

5.2.2.3 Rated Current Hold-In Test

The rated current hold-in test verifies that an MCCB can carry its rated current without tripping. This is usually performed on breakers that have been tripping under normal operating conditions, where nuisance tripping may not be tolerable, or when overheating is suspected. The breaker is mounted in free air with its poles connected in series. The rated current is applied for a particular amount of time (e.g., 30 minutes) and the breaker observed; no tripping should occur. If tripping does occur, the connections are checked for signs of undue heating. Corrective action generally entails replacement.[5.2, 5.3-5.5, 5.12, 5.14-5.18, 5.20]

5.2.2.4 Overload Trip Test

The overload trip test is also called the inverse-time trip test, overload tripping test, 300% overload trip test, time delay overcurrent trip test, and overcurrent trip test. The test is used to verify the performance of the thermal tripping element on thermal-magnetic breakers. The verification is done by separately applying (to each pole) a select certain percentage of rating (e.g., 300% of the breaker rating per pole). Failure to trip within the desired overcurrent band is one of the more common failure types. Periodic testing (e.g., once per refueling outage on a rotational basis) has been effective at identifying these problems. This test does not, however, verify that the MCCBs meet their applicable characteristic trip curves (because of the difficulty in repeating controlled factory conditions in the field), but does confirm the basic operability of the MCCB thermal trip unit.[5.2, 5.3-5.5, 5.12, 5.14-5.18, 5.20, 5.21]

5.2.2.5 Instantaneous Magnetic Overcurrent Trip Test

This test verifies proper operation of the instantaneous trip unit. In essence, this test simulates a short-circuit condition. The test can verify either that the instantaneous trip feature is functional (which is beneficial for routine testing) or the actual trip point of the MCCB (depending on application). Failure of the instantaneous overcurrent trip function is also a fairly common failure mode in MCCBs, and this test is considered important for ensuring that the instantaneous trip unit is functional.

During the test, each pole of the breaker is tested individually by either the "run-up" or "pulse" method. Specific details of each method are beyond the scope of this discussion; however, the "run-up" method requires simpler and less expensive equipment, yet also requires a skilled operator to recognize the relationship between actual current and meter indication. The "pulse" method produces more accurate data and can be used to duplicate published magnetic trip values; however, it may be subject to other errors introduced by the measurement process.[5.2, 5.3-5.5, 5.12, 5.14-5.18, 5.20, 5.21]

5.2.2.6 Shunt Trip Test

Shunt trip units are accessory devices used to trip open an MCCB under conditions other than overcurrent (for example, upon receipt of control signals). They are used in a limited number of applications. Testing of the shunt trip device may be functional in nature (confirms that the shunt trip mechanism is operational and will operate as required to trip the breaker) or diagnostic (measuring specific device parameters such as coil resistance or pickup voltage). Generally, these devices are internal to the breaker case and are only functionally tested.[5.2, 5.3-5.5, 5.12, 5.15-5.17]

5.2.2.7 Undervoltage Trip Test

The undervoltage trip test is used to confirm the performance of the undervoltage trip unit associated with the breaker (if installed). Like shunt trip devices, these are used in a limited number of applications. Similarly, testing of this unit is usually functional in nature; it determines whether or not the breaker will trip upon loss of/degraded voltage and remain open upon subsequent restoration.[5.2, 5.3-5.5, 5.12, 5.15-5.17]

5.2.2.8 Testing of MCCB Auxiliary Contacts

Breaker auxiliary contacts are accessory devices that are utilized to indicate MCCB position remotely and provide alarm, control, and interlocking functions. These devices are visually inspected for signs or wear or degradation, and functionally tested to ensure proper operation.

5.2.2.9 Corrective Maintenance of MCCBs

As discussed in Section 3.4, MCCBs are sealed devices and are usually not intended to be disassembled and repaired. When the MCCB is no longer functional, the circuit breaker should be discarded and replaced. Unless specifically allowed by the manufacturer, MCCBs should not be opened for repair (opening for determination of the cause of failure is appropriate, however). If any of the aging management activities described above detects age-related degradation of the MCCBs (e.g., cracks are observed in the casing, the breaker ratings have drifted to unacceptable levels, indications of overheating (discoloration) are identified, or the breaker fails a functionality or trip test), the circuit breaker should be replaced or the manufacturer consulted before restoring the circuit breaker to service. In some cases, testing of other breakers of the same model/manufacturer used in similar plant applications may be warranted to evaluate potential generic problems with that specific equipment. For example, if a previously unrecognized failure mode is suspected, the affected breaker(s) should be disassembled to determine the cause. If this failure mode has possible generic implications, then other breakers of the same model/manufacturer should be evaluated.[5.2, 5.3-5.5, 5.10-5.12, 5.15-5.17, 5.19, 5.22, 5.23]

5.2.3 Magnetic Starters/Contactors

The common maintenance practices currently used to maintain the magnetic starters/ contactors are visual inspection, cleaning, and operability checks and tests that include manual operation of the contactor and a contactor coil pickup/dropout test. Contact life and required frequency of inspection both depend on the severity of the device's service environment and operational frequency. In general, contactors will be inspected and their operability verified during each scheduled maintenance period (approximately once every 5 to 8 years). More severe service environments may warrant increased inspection frequency. If the operation of the contactor is suspect, it may be tested using the pickup/dropout test or simply replaced.

Contact surfaces, springs, and coils are visually inspected (when accessible) for signs of pitting, wear, overheating, beading on the contact or magnet assembly, and discoloration. Pitted contact surfaces may or may not interfere with proper operation, depending on such factors as contact pressures and the presence of sufficient contact surface facing. Contacts are replaced when the silver tip is eroded and the contact tip support is exposed. Proper spring forces are necessary to allow the contactor to properly carry and interrupt electrical power. Contact springs are inspected for signs of overheating (blackening); if evidence of overheating exists, the contact pressure is then verified. (Note: On some equipment, contact pressure can be measured by mechanically closing the contactor/starter and using a spring scale to measure the force necessary to separate the contacts.) A feeler gauge (or other similar device) may be used to verify contact tolerances.

Manual operation of the contactor/starter components is performed to detect any binding of the moving parts and to ensure the latch and mechanical interlock mechanisms, if used, are operating properly. Bolted connections, nuts, screws, and wires are also inspected for tightness and damage.

Contactor pickup/dropout voltage testing may be performed to verify the operability/ performance of the contactor coil. Significant changes in pickup and dropout voltages indicate coil deterioration, binding, or changes to the magnetic circuit.

Magnet mating surfaces must be kept free of accumulated dirt or dust. Common maintenance practices currently provide that an inspection for dirt, dust, moisture, and contaminants be conducted. In addition, the contactor is manually cycled several times, which helps distribute lubricants (if used) and clean the contact surfaces through operational wiping.[5.5, 5.6, 5.8, 5.9, 5.11, 5.13, 5.24]

5.2.4 Thermal Overload Relays

Common maintenance practices currently used to maintain thermal overload devices are visual inspections, component adjustments, operability checks and testing, and cleaning. Visual inspection of the relay will help control degradation of the relay materials (such as thermal degradation of the phenolic heater support block) and identify fatigue cracking, overheated/high resistance connections, and contact surface degradation (where contacts are accessible for inspection). Inspection and operability testing are normally conducted at each maintenance interval (every 5-8 years on average); however, as with other MCC components, indications of problematic operation may warrant more frequent testing or even replacement.

A common operability test for thermal overload relays is the thermal overload device functionality test; this subjects the thermal overload device to its full load current and subsequently to its ultimate trip value to verify proper response. This test verifies adequate performance of the installed heater elements. Another operability check conducted on the overload relay is a manual tripping of the relay to detect any mechanism misalignment/binding and to ensure that the overload resets properly. Some maintenance procedures also require that the operator verify the status of the contactor coil (energized/de-energized) during the operability check; operation of the overload relay is supposed to de-energize the contactor coil.

Resistance checks may also be performed to help detect high resistance electrical connections. Common maintenance practices also require that connections are inspected and tightened if necessary.

External cleaning of the overload relay removes dirt and contaminants, thereby reducing the possibility of mechanism binding or surface degradation caused by foreign material.[5.3, 5.5, 5.7, 5.9, 5.10, 5.11]

5.2.5 Miscellaneous Relays

Common maintenance practices currently used to maintain MCC relays are visual inspection, operability checks and testing, resistance/continuity measurements, component adjustments (component tolerances, relay calibration, etc.), and cleaning. Visual inspection and relay operability checks help control thermal degradation/organic material breakdown, wear, fatigue, insulation degradation, and the deterioration of relay lubricants. Visual inspection will usually detect physical damage, dirt, corrosion or oxidation of electrical connections, signs of overheating and damaged insulation, dried or gummed lubricants, and contact surface degradation (if the contact surfaces are readily accessible). Operabili y checks will verify the freedom of movement of the armature and contact assembly, as well as the functionality of special-purpose relays (such as a pneumatic time delay relay). In many cases, operability checks are performed to determine relay status; if sluggishness or other problems are noted, then subsequent replacement, disassembly, and/or testing of the relay will be performed. It should be noted that most relays are simply replaced upon degradation or failure.

Resistance and continuity testing will indicate the status of the coil windings, contact surfaces, and electrical connections. Component adjustments are performed when operation or aging of the relay has altered critical tolerances associated with relay subcomponents or has otherwise affected the calibration of the device. Cleaning may help prevent deterioration and wear of components and contamination of the contact surfaces; however, many relays (especially the newer models) are essentially sealed units and are not susceptible to dirt or contaminant intrusion.[5.5, 5.7, 5.9, 5.10, 5.11]

5.2.6 Control Transformer

The common maintenance practices currently used to maintain the control transformer are visual inspection, insulation resistance testing, resistance/continuity testing, component adjustments (verification of the tightness of connections), and cleaning. Visual inspection for physical damage, dirt, corrosion, or degraded insulation is conducted. Testing of the insulation resistance may also be conducted to verify the integrity of the winding insulation. Resistance testing of the connections and windings may be performed to detect high-resistance connections or open windings. Transformer external surfaces are cleaned to remove dirt and contaminants; mounting hardware is checked to ensure that the transformer is securely affixed to the cabinet and connections are inspected for tightness and any signs of overheating. In general, control transformers are inspected during each scheduled maintenance period (i.e., 5-8 years); testing is normally only conducted when the functionality of the component is in doubt. As with other similar MCC components, failed control transformers are typically replaced rather than repaired. [5.5, 5.7, 5.9, 5.10]

5.2.7 Terminal Blocks

The common maintenance practices currently used to maintain MCC terminal blocks are visual inspection, adjustments (tightening of electrical connections), and cleaning. The MCC terminal blocks and terminals are visually inspected for cracks, chipping, evidence of surface tracking or overheating, corroded/oxidized terminals, and other physical damage. This inspection is normally conducted during scheduled maintenance periods or when corrective maintenance is performed.

The combination of visual inspection and verification of the electrical connections completely controls two of the primary terminal block aging mechanisms: loss of electrical and mechanical properties and loss of electrical connection integrity. Visual inspection for embrittlement and cracking prevents insulation failure caused by a loss of mechanical properties. Insulation resistance testing prevents in-service failure caused by a reduction in insulation properties. Tightening, inspection, and resistance testing of the terminal controls thermal degradation of the terminal block because of high localized temperatures generated from high resistance connections. Cleaning of the terminal block surfaces and terminals helps prevent the buildup of dirt, contaminants, and moisture, which may lead to surface tracking or dry-banding as well as deterioration of the physical integrity of the unit. (Note: Some terminal blocks may be equipped with integral fuse holders; these devices are addressed in Section 5.2.9 below.)[5.1, 5.3-5.9, 5.12, 5.22, 5.23, 5.25]

5.2.8 Control Wiring

Common maintenance practices currently used to maintain MCC control wiring are visual inspection and cleaning. Wiring is visually inspected for insulation or jacket cracking, cutting, chafing, or overheating; corroded, oxidized, or loose terminations; and physical damage. In addition, the wiring is visually inspected for proper routing and support. The tightness of connections is also checked. Cleaning of the insulation removes contaminants and dirt that may accelerate insulation deterioration.[5.3-5.7]

5.2.9 Fuse Holders

Common maintenance practices used to maintain fuse holders in MCCs are visual inspection and cleaning. Fuse holders are visually inspected for signs of fatigue stress, loose or damaged parts, corrosion or oxidation of fuse contact surfaces and electrical connections, and physical damage (depending on the type of fuse holder). Fuse holders with fuse failure indicators are inspected for damage or burnout of the indicating filament/diode. Suspect contact surfaces or connections can be tested for resistance. Cleaning of contact and electrical connection surfaces helps reduce electrical resistance and limit thermal degradation of surrounding materials caused by high resistances.[5.3, 5.4, 5.6, 5.7, 5.11]

5.3 Less Common Maintenance and Surveillance Techniques and Programs Used, Including Refurbishment and Replacement

Less common maintenance and surveillance techniques applied to MCCs and their components include infrared thermography and component replacement/rehabilitation. These techniques are discussed in the following sections.

5.3.1 Infrared Thermography

Infrared thermography is a maintenance and surveillance technique used to detect and evaluate component heating. All materials radiate infrared energy. The hotter the component, the more energy radiated. Infrared detectors can sense infrared radiant energy and produce electrical signals proportional to the temperature of the targeted component. The instruments use optics to gather and focus energy from the targets onto infrared detectors. Instruments are currently available that have sensitivities on the order of ±0.1°C [±0.78°F] with rapid response times.[5.19] Infrared detectors are available in two basic types: spot measuring and scanning. The spot measuring devices are pointed at a target area and provide either an analog or digital indication of the temperature of the target. The scanning devices provide a pictorial representation of the temperature of the area under observation. Variations in intensity or color of the image indicate the relative temperature. Some systems provide capability to store images for comparison with subsequent measurements or evaluation. Reference 5.19 provides a detailed description of the systems. The advantage of using infrared thermography on MCCs is that hot spots can be observed while the equipment is energized. Thermographic inspection requires the access doors to the control centers to be open and bus housing covers to be removed to limit potential masking of energy radiated by overlaying components.

For MCCs, spot measuring devices would be of limited use in that manual scanning of components and tedious recording of individual component temperatures would be required. Scanning systems with recording capability are much easier to use because a hot spot can be readily compared with surrounding components and sections of the system to determine what is causing the hot spot. If thermographic scans were performed previously, comparisons can be made and variations in thermal images can be evaluated to determine if hot spots are developing or changing. In MCCs, abnormally hot spots in any exposed and accessible insulated breaker faces and surfaces next to the breakers, line and load connections, heaters, terminal blocks, or control wires could indicate loose, crimped, damaged, or corroded connections that would cause overheating and subsequent insulation damage. Identifying such conditions could allow correction of the condition before significant insulation damage occurred. At a minimum, more frequent observation of the suspect component could be performed to determine if the condition is stable or worsening.

Although infrared thermography is a valuable tool for evaluating the condition of components, it is not a panacea and should be used in conjunction with other techniques. Certain aging mechanisms do not produce significant amounts of heat and may not be easily identified from thermal scans (see Section 3.6.4.2 of this guideline). For example, surface tracking of insulators may not be observable by thermography; however, indications of tracking may be observable by visual inspection. Likewise, chaffing of insulation from rubbing against a bracket or support would not cause heating, but could be observed by visual inspection. Also, use of thermography requires a skilled operator who understands the technique, the materials being evaluated, and the equipment under observation. Distance from the target and the target's emittance, reflectance, orientation, and size all affect the thermal image. For example, a shiny surface will reflect infrared radiation from other areas and can substantially affect results.[5.19] Therefore, interpretation of results may require considerable skill or the operator may have to modify the target by covering it with a black tape. Also, the operating status of the control center will affect results. If thermography is performed while a bus or component is loaded in a manner other than normal (e.g., major loads out of service), the resulting evaluation may not indicate actual problems. Therefore, the operating status of the bus and its loads need to be considered when comparing and evaluating results.

Knowledge of thermography techniques and the types of aging mechanisms that could be indicated by heating and the combining of thermography with other proven techniques such as visual inspection would make thermography a valuable tool for evaluating MCC conditions.

5.3.2 Replacement/Refurbishment

Replacement and refurbishment are two alternative maintenance techniques that may be used to control MCC aging. These techniques are described below.

Replacement

In most cases, failed or deteriorated MCC components (such as MCCBs, relays, contactors/starters, thermal overloads, control transformers, terminal blocks, wires, fuse holders, and switches) are replaced as opposed to repaired. This practice is a result of a number of considerations, including the expense of repair versus replacement, the amenability of certain components to being repaired (i.e., MCCBs and other components may be sealed, thereby precluding maintenance or repair), and the relative importance of the required function provided by the component to the load being served. The longer-lived components (such as the housing and bus system) rarely fail, and are generally repairable if deterioration is identified.

Because of the variety of different functions and operating conditions for components within a given MCC, failures of replaceable components generally occur at differing rates. For example, a contactor may experience substantially more cycles over a certain period of time than the circuit breaker associated with the same load; accordingly, the contactor may fail more frequently than the breaker (despite the contactor's greater endurance rating). Components are therefore continually replaced throughout the life of the MCC based on their individual operating conditions and limitations.

Several additional considerations exist for component replacement, including the certification and environmental qualification of the replacement parts, as well as component obsolescence. Use of in-kind replacements is generally a preferred method, because modifications and design verification are not necessary. However, use of non-in-kind parts requires confirmation of design and critical component characteristics prior to use. One-for-one component replacement (i.e., replacement with an identical model/type) is therefore usually not problematic. One strategy used is to replace failed or aged safety-related components with those taken from existing stock or from identical non-safety-related applications that were procured to the same requirements; this provides the plant with a limited, but qualified supply of replacement parts. However, the substitution of different or upgraded components (i.e., replacement of a thermal-magnetic MCCB with a newer, more capable solid-state unit) can be more troublesome; commercial grade dedication and/or environmental qualification of the replacement components must be performed to allow their use in safety-related applications. Special analysis and testing are then necessary before the new devices can be placed in service.

Another consideration during replacement of components is the possibility of procurement of counterfeit parts; a variety of parts (ranging from relays to entire metal-clad circuit breakers) has been discovered to be counterfeit or not in conformance with applicable industry and manufacturer's standards for such components. This is of particular concern in those applications where component performance is essential to the fulfillment (or non-preclusion) of a required plant function. Hence, an effective program for the management of MCC aging must necessarily ensure both the authenticity of the components used as replacement parts and their adherence to applicable performance and material standards. These requirements can be met using a variety of techniques, including examination of the equipment upon receipt (specifically, examination of the nameplate data, appearance/condition of the component compared with known authentic units, comparison of the shipping documentation with the component data, etc.), verification of equipment origin (i.e., contacting the manufacturer to ensure that the equipment was in fact procured from their facility), and performance testing prior to installation.

The NRC states that the reliability and capabilities of refurbished MCCBs, although not directly related to any aging mechanism, is a serious concern based on inadequacies of many of the refurbished units tested. NRC Bulletin 88-10, "Nonconforming Molded-Case Circuit Breakers,"[5.26] was issued in response to a large number of reports dealing with the refurbishment and counterfeit rating labels of MCCBs (first addressed in NRC Information Notice 88-46, "Licensee Report of Defective Refurbished Circuit Breakers,"[5.27]). Information Notice 88-46 and Supplements 1, 2, 3, and 4[5.28, 5.29, 5.30, 5.31] thereto list circuit breaker distributors and companies suspected of selling used or refurbished circuit breakers, parts, and accessories as new.

Refurbishment

Refurbishment refers to the process by which the components associated with a given MCC or cubicle are reconditioned or restored. This process can be distinguished from replacement (described above) in that replacement merely substitutes a new component for a failed one, whereas refurbishment seeks to upgrade the entire control center or cubicle, not necessarily based on any one failure. Refurbishment is generally applied to MCCs using one of two methods. In the first method, MCC subassemblies (such as cubicles or buckets) are restored to a near-original condition* by the in-kind replacement of components. This equates to a one-for-one replacement of all such components, usually performed by plant maintenance personnel. In contrast, a second method of refurbishment substitutes components from other manufacturers which are similar in function to the originals. Usually, this type of procedure is conducted by a third party at a remote repair facility; often, the entire bucket will be removed and shipped to the repair facility where its components are replaced with aftermarket equivalents or another manufacturer's bucket components appropriately mounted in the existing bucket system. Generally, the refurbisher takes the responsibility for environmental and seismic qualification of the refurbishment design.

In addition, the periodicity or frequency of refurbishment may be determined (independent of method) based on either a fixed time interval or equipment condition. The fixed time interval approach uses a predetermined time period (often between 10 and 20 years depending on severity of the equipment operating environment, function of the load served by the MCC, etc.), whereas the condition-based approach relies on the observed condition of the installed equipment as a determinant of when to refurbish. Under condition-based programs, the frequency of refurbishment may vary widely; those applications experiencing slow rates of component

* In many cases, components that were originally used in the subassembly being refurbished are either no longer available or have been replaced by newer equivalents. In these instances, the newer models are substituted directly for the older components.

degradation may only be refurbished once or twice during their installed lifetime, while applications experiencing more rapid degradation will be refurbished more frequently as required.

Considerations in the determination of a periodic refurbishment schedule include prior historical performance of the equipment (both plant-specific and industry-wide, if available) as well as scheduled outages or maintenance. Condition monitoring can usually be accomplished during routine maintenance; however, the condition of individual components within the MCC is often difficult to evaluate directly (this is especially true of sealed components such as MCCBs). Equipment-specific information regarding the past performance of the MCC or its components may also be used as part of this evaluation. For example, a substantially increasing rate of component failures associated with a given MCC or cubicle over a period of time (with no other changes in operating conditions or environment) may indicate the need for refurbishment of the equipment. Hence, condition-driven refurbishment should be based on all relevant indications of MCC condition available to the maintainer. Refurbishment by a third-party vendor may also be predicated on the increasing difficulty of obtaining replacement parts from original equipment manufacturers.

5.4 Programs and Techniques Applied to Components

5.4.1 Evaluation of Current Programs

Section 5.1 lists the three criteria that determine if a maintenance program is effective in managing aging. With respect to Criterion 1, procedures from a number of power plants were reviewed. These reviews indicate that MCC maintenance programs are documented. These procedures also indicate that the programs are implemented under plant onsite review committees and controlled by plant administrative procedures.

With respect to Criterion 2, the maintenance procedures were reviewed to determine if they were effective in controlling and mitigating the effects of the aging mechanisms identified during the operating history review described in Section 3.6 and in Chapter 4. These procedures are described in Section 5.2. The results of this review are summarized in Table 5-1. The procedures required inspection and maintenance activities to be performed that would control each of the aging mechanisms identified in Section 4.2. The results of the operating history review described in Section 3.6 were evaluated to determine if further consideration or attention should be given to inspection and maintenance of certain components. In general, the review indicated that current maintenance programs using procedures that are consistent with Section 5.2 and Table 5-1 are effective in managing aging of MCCs. Conditions requiring plant-specific confirmation of effectiveness are described in Section 5.4.2.

Each maintenance procedure was also reviewed for compliance with Criterion 3 (which specifies the need for specific acceptance criteria and timely corrective action). Each procedure contains acceptance criteria against which the need for corrective action is to be evaluated and required timely corrective action to be taken when the acceptance criteria are not met. In Table 5-1, activities requiring tolerances and acceptance criteria to be contained in procedures are so indicated.

Table 5-1. Common Maintenance and Surveillance Techniques

MCC Components	Aging Mechanism(s)	Activities That Mitigate Effects of Aging Mechanisms	Required Acceptance Criteria
MCC Structural Components (including buswork, insulation, and housing)	Loss of insulator mechanical and insulating properties	Visual inspection for insulation tracking paths, signs of overheating, surface contamination, surface irregularities, cracking, embrittlement, and discoloration; cleaning; insulation resistance testing	Insulation resistance
	High resistance electrical connections,* loss of bolt integrity	Visual inspection of MCC buswork, ground bus, and chassis ground for loose or overheated electrical connections; warping; verification of tightness of connections and buswork bolts; IR thermography	Torque specifications
	Loosening/loss of fastener components	Verification of proper torque on the housing bolts and hardware; replacement as required	Torque specifications
Molded-Case Circuit Breakers**	Deterioration of contact surfaces	Periodic operation for removal of contaminants and oxidation from contact surfaces; individual pole resistance test, operational testing	Main contact open/ close; pole resistance; satisfactory performance on operational tests
	Material fatigue and embrittlement	Visual inspection of MCCB casing for cracks, chipping, or signs of overheating	
	Wear or binding of internal MCCB components	Operational testing, freedom of movement of operating mechanism	
	Wear of external operating handle	Visual inspection for wear, inadequate lubrication, loss of tolerances; lubrication, cleaning, or adjustment; operability testing	Tolerance specifications; operational performance
	Deterioration of bus/cable connections	Visual inspection and mechanical verification of MCCB bus and load terminations	
	Variation of setpoint of bimetallic trip element	Operational trip test	Meets time-current curve; trips on demand

* The aging mechanism of high resistance electrical connections is applicable to all power path components within the MCC enclosure; hence, it will only be described for this component.

** Includes the MCCB as well as the external operating handle and linkage.

Table 5-1. Common Maintenance and Surveillance Techniques (continued)

MCC Components	Aging Mechanism(s)	Activities That Mitigate Effects of Aging Mechanisms	Required Acceptance Criteria
Molded-Case Circuit Breakers (continued)	Deterioration of lubricants	Verification of the freedom of motion of the operating handle/mechanism during cycling	
	Current-limiting fuse* failure	Functional trip test	
	Surface current tracking/loss of insulating properties	Visual inspection of insulation for tracking paths, signs of overheating, surface contamination, surface irregularities, cracking, embrittlement, and discoloration; cleaning of internal components and insulating surfaces; insulation resistance testing**	
Magnetic Contactor/Starter	Insulation deterioration	Visual inspection of coils for damage, deterioration, and signs of overheating or localized burning; verification of freedom of armature movement (identifies melting of coil materials)	
	Prolonged energization	Visual inspection of coil and other components for signs of overheating, flowing, or burning of materials	
	Cyclic fatigue of armature/contact assembly	Visual inspection of the coils for cracks, damage, and verification of the freedom of motion of the armature	
	Wear/binding of contactor, auxiliary contacts, or interlock mechanisms	Visual inspection for dirt, contaminated lubricant, wear or loss of tolerances of components; operations testing; cleaning, adjustment, lubrication, and replacement as required	Contact and component tolerances; operational performance
	Contact surface degradation	Cleaning/burnishing of contacts; visual inspection for cracking, burning, pitting, wear, and corrosion; refinishing or replacement if necessary	Contact resistance
Thermal Overload Relay	Degradation of heater or bimetallic element	Visual inspection of elements for overheating or other damage; operation testing; replacement	Overload trip at desired setpoint

* Only applicable to MCCBs with current-limiting fuses installed.

** These activities are possible only for MCCBs with accessible internal components.

Table 5-1. Common Maintenance and Surveillance Techniques (continued)

MCC Components	Aging Mechanism(s)	Activities That Mitigate Effects of Aging Mechanisms	Required Acceptance Criteria
Thermal Overload Relay (continued)	Binding of mechanical components	Verification of component freedom of movement; inspection; lubrication, adjustment, or replacement	
	Contact surface degradation	Visual inspection; cleaning or burnishing	
	Thermal degradation of organic materials	Visual inspection of heater support and other relay components for overheating, embrittlement, cracking or other damage; cleaning or replacement as required.	
Miscellaneous Relays	Prolonged energization; organic material breakdown	Visual inspection of coil and other relay components for overheating, burning, or flowing of materials	
	Contact surface degradation	Visual inspection for corrosion, wear, or oxidation of contact surfaces; resistance testing; cleaning/replacement as required	Contact resistance
	Wear and binding of contact mechanism	Visual inspection; freedom of movement, operational tests	Operational requirements
Control Transformers	Insulation degradation	Inspection of overheating, cracking, or burning of insulation; IR thermography; replacement	Insulation resistance
	Conductor failure	Continuity/resistance measurement; replacement	Winding continuity
Terminal Blocks	Degradation of organic materials	Visual inspection of terminal block for signs of overheating, embrittlement, cracking, or other damage; cleaning or replacement as required	
	Degradation of hardware	Visual inspection for terminals, nuts, screws, sliding links, fuse holders (if equipped), and mountings for damage, deterioration, or loss; tightening, repair, or replacement as required	
	Loss of insulating properties	Visual inspection of block for tracking paths, overheating, surface contamination, surface irregularities, cracking, embrittlement, and discoloration; cleaning or replacement as required	Insulation resistance
Control Wiring	Failure of insulation and/or conductor	Visual inspection of insulation for cutting, chafing, cracking, overheating; inspection for bending, twisting, breaking of conductor; cleaning and replacement as required	

Table 5-1. Common Maintenance and Surveillance Techniques (continued)

MCC Components	Aging Mechanism(s)	Activities That Mitigate Effects of Aging Mechanisms	Required Acceptance Criteria
Fuse Holders	Fatigue of fuse clip	Visual inspection for fatigue or wear of fuse clip and adequate pressure on ferules; replacement as required	
	High resistance/worn contact surfaces	Visual inspection for signs of oxidation, corrosion, contaminants, or overheating; cleaning/burnishing; replacement	

The review of the significant aging mechanisms versus established maintenance practices indicated that all significant aging mechanisms are considered and controlled with a limited number of potential exceptions that are discussed in Section 5.4.2. This conclusion is supported by the review of operating history that indicates few repetitive failures associated with any one specific control center component for a given manufacturer's model line (or for all manufacturers collectively).

5.4.2 Potentially Significant Aging Mechanisms Not Fully Addressed by Current Programs

Comparison of the aging mechanisms identified in the operational review contained in Section 4.2 with the MCC maintenance methodology described above verified that nearly all component/aging mechanism combinations are addressed by current programs. However, the results of the failure data analysis conducted in Section 3 would indicate that for certain components, not all MCC component aging mechanisms are completely controlled by these programs. Based on limitations in the failure data, significant fractions of the total number of failures recorded for each component could not be accurately classified with respect to failed subcomponent and/or failure mode. Additionally, the aging mechanism(s) contributing to or causing the failure could often not be determined. As a result, any attempt at identifying those aging mechanisms which are not fully controlled would suffer from potentially large inaccuracies. Despite these limitations, however, some general observations as to the components, conditions, or environments for which aging does not appear to be fully controlled can be made. The following paragraphs describes those cases where aging does not appear to be fully addressed by current programs, and additional efforts may be necessary.

Conditions for a Fully Acceptable Program

If the MCCs are located in a mild environment area (not subject to an elevated temperature/steam condition or elevated radiation levels under accident conditions), are in areas where temperatures do not exceed 40°C [104°F] for significant periods, are not exposed to high concentrations of dust or other contaminants, and their individual components (i.e., starters, contactors, etc.) are not subjected to a high* number of operating cycles, then maintenance and surveillance procedures that are consistent with those described in Section 5.2 and Table 5-1 will be effective in managing aging, with the following possible exceptions:

General Exceptions

- Molded-Case Circuit Breakers. Failures associated with molded-case circuit breaker components comprised the single highest fraction of failures noted in the study (36% of all failures). A substantial fraction of all breaker-related failures (39%) were detected during operations, indicating that not all aging mechanisms associated with these components are completely addressed by current maintenance practices.

- Breaker Operating Handles/Linkages. Many of the manufacturers' MCCs appeared to suffer from problems associated with the external breaker operating handle (approximately 7% of all failures noted). This may indicate that aging mechanisms for the operating handle (i.e., wear of components and deterioration of lubricants) are not completely controlled. Failure of the external operating handle could, under certain circumstances, adversely impact the required function of the associated load during normal or accident conditions.

- Starter/Contactor Mechanical Assemblies. As indicated in the industry failure data presented in Section 3.6, failures of starter/contactor mechanism (including the main contactor, interlock, and auxiliary contact assemblies) were prevalent. Of all starter/contactor-related failures, 41% were detected during operations. A significant fraction of all MCC failures noted (for all manufacturers) were related to binding or sticking of the auxiliary contacts, indicating that this aging mechanism may not be fully controlled.

It should also be noted that other some components such as miscellaneous relays and control transformers exhibited relatively high rates of detection during operation (potentially indicating that all aging mechanisms for that component are not completely controlled); however, since the overall proportions of these failures were small, they were not considered significant.

As indicated above, MCCs located in the following environments will require further plant-specific activities, which are described in Section 6.

- Exposure to accident temperature/steam or radiation conditions that require environmental qualification and definition of qualified lives for subcomponents.

- Exposure to normal temperatures in excess of 40°C [104°F] for significant periods.

* The definition of a high number of cycles will vary based on the type of component under consideration. For example, contactor assemblies are generally designed for a hundred-thousand cycles or more during their lifetime, whereas MCCBs may be designed for only several thousand cycles. Applicable standards and manufacturer's guidance should be consulted to determine the design cyclic rating for an individual component.

- Service conditions that require a high* number of operating cycles in relation to the manufacturer's design cyclic rating for each individual MCC component.

Manufacturer-Specific Exceptions

The following manufacturer-specific exceptions (in addition to the general exceptions described in the preceding paragraph) were noted, and may warrant additional scrutiny:

- Gould/ITE MCCs appear to exhibit a high percentage rate of molded-case breaker failure; more than 53% of all reports related to Gould/ITE MCCs concerned failures of molded-case breakers.

- General Electric MCCs appear to have a high rate of starter/contactor auxiliary contact failure in relation to other components; 22% of all GE failures (77 of 352 reports) were related to the contactor auxiliary contact assemblies.

The above listed conditions indicate that additional plant-specific review of procedures and overall programs may be warranted to ensure their effectiveness; see Section 6 of this guideline for further information.

5.5 Comparison with NPAR Results

The NRC Nuclear Plant Aging Research (NPAR) program has evaluated the aging of numerous components, including motor control centers. As a result of this evaluation, NUREG/CR-5053, "Operating Experience and Aging Assessment of Motor Control Centers," was generated.[5.32] NUREG/CR-5053 was used as an input to Sections 3.6.4 and 3.6.5 of this report. Comparison of the findings of NUREG/CR-5053 and this guideline is discussed in the following paragraphs.

Examination of subcomponent failures as documented by NPRDS in both the NPAR document and this guideline (Figures 3-29 and 3-14, respectively) indicates a substantial degree of consistency; as indicated in the figures, the fraction of overall failures caused by each subcomponent are roughly equal, with the exception of contactors (10% for NPAR vs. 33% for this study). It should be noted, however, that the component categorization schemes for the two studies are somewhat different. For example, the NPAR study uses separate categories for coils, relays, and contactors; in some cases coils are subcomponents of contactor and relay assemblies. Hence the higher percentage of contactor failures noted in this guideline may partially be because of inclusion of so-called "coil" failures within the contactor category.

Comparison of subcomponent failures as documented by LERs in the NPAR document and this guideline also show a good correlation (see Figures 3-30 and 3-26, respectively). Both

* The definition of high cycle will vary based on the individual component; for example, contactor assemblies may be designed for a hundred thousand or more cycles, whereas molded case breakers may be designed for only several thousand cycles. Applicable standards and manufacturer's guidance should be consulted to determine the endurance rating for a given MCC component.

studies indicate roughly equal percentages of breaker, contactor, relay, terminal and wiring, and control transformer failures; however, some disparity does exist with respect to bus bar/housing failures. As this subcomponent category is not listed in the NPAR data, it is difficult to account for this discrepancy. In addition, Figure 3-30 incorporates two sources of data (i.e., LER and Nuclear Power Experience (NPE) data), which may also account for some of the differences between the results.

In sum, the findings of NUREG/CR-5053 are highly consistent with those discussed in Sections 3.6.2 and 3.6.3 of this guideline. Both studies indicate that breaker, relay, and contactor failures are most prevalent for MCCs. The primary causes of subcomponent failure identified in both documents are also similar, despite differences in definition and categorization.

5.6 References

5.1 10 CFR Part 54.21, "Requirements for Renewal of Operating Licenses for Nuclear Power Plants — Contents of Application — Technical Information," Federal Register, Vol. 56, No. 240, December 13, 1991, p. 64978.

5.2 EPRI NP-7410-V3, "Breaker Maintenance — Volume 3: Molded Case Circuit Breakers," September 1991.

5.3 Proprietary Plant Procedure, "Molded Case Circuit Breaker and Controller Inspection and Preventive Maintenance Procedure," Revision 3, March 5, 1986.

5.4 Proprietary Plant Procedure, "Inspection of Molded Case Circuit Breakers and Manual Fused Switch Panels," Revision 1, October 4, 1988.

5.5 Proprietary Plant Procedure, "Molded Case Circuit Breaker and Thermal Overload Relay Testing," Revision 1, August 23, 1990.

5.6 Proprietary Plant Procedure, "Five Year Interval 480 Volt MCC Inspection and Test," Revision 1, February 20, 1992.

5.7 Proprietary Plant Procedure, "General Inspection of Switchgear, Motor Control Centers and Electrical Enclosures," Revision 1, February 5, 1990.

5.8 Proprietary Plant Procedure, "Disassembly and Reassembly of Square "D" Motor Control Centers," Revision 5, August 13, 1990.

5.9 Proprietary Plant Procedure, "Installation, Operation, and Maintenance Manual for Motor Control Center Cubicles," Revision 0, July 25, 1988.

5.10 Proprietary Plant Procedure, "480 V Motor Control Center and Molded Case Circuit Breaker, "Revision 0, April 20, 1988.

5.11 Proprietary Plant Procedure, "Maintenance of Motor Control Centers," Revision 0, August 14, 1989.

5.12 Proprietary Plant Procedure, "Sixty Month 600 Volt Breaker Inspection and Preventive Maintenance," Revision 3, November 14, 1988.

5.13 ITE Imperial Corporation, Motor IB-6.10-1, Motor Control Center Series 9600, Instructions and Renewal Parts.

5.14 Westinghouse, Electrical Maintenance Hints - Volume 2, "Industrial Equipment Maintenance," 1984.

5.15 Proprietary Plant Procedure, "Westinghouse Molded Case Circuit Breakers Thermal and Instantaneous Trips Testing," Revision 0, October 23, 1990.

5.16 Proprietary Plant Procedure, "Molded Case Circuit Breakers Inspection and Test," Revision 5, March 3, 1992.

5.17 Proprietary Plant Procedure, "Molded Case Circuit Breaker Testing," Revision 9, October 18, 1991.

5.18 Proprietary Plant Procedure, "Molded Case Circuit Breaker Test," Revision 1.

5.19 EPRI Report NP-6973, Infrared Thermography Guide, Electric Power Research Nuclear Maintenance Applications Center, 1990.

5.20 Square D Circuit Breaker Application Guide, "Field Testing Industrial Molded Case Circuit Breakers."

5.21 Proprietary Plant Procedure, "AC and DC Molded Case Circuit Breaker Test Procedure," Revision 11, January 7, 1991.

5.22 Proprietary Plant Procedure, "Containment Penetration Conductor Overcurrent Protective Devices Verification," Revision 3, March 13, 1992.

5.23 Bechtel Power Company, Instruction Manual Operation-Maintenance Instructions and Parts Catalog for AC Motor Control Center IC7700, GEK-73389, Volume 1, Order Number 10407-13-EM-018.

5.24 Westinghouse, "Instructions for A200, A210, A250 Size 5, 2, or 3 Pole Motor Controller Non-Reversing or Reversing," I.L. 17054A.

5.25 General Electric GEH-2614F, "Installation and Maintenance of 7700 Line Motor Control Center."

5.26 NRC Bulletin 88-10, "Nonconforming Molded-Case Circuit Breakers," November 22, 1988.

5.27 NRC Information Notice 88-46, "Licensee Report of Defective Refurbished Circuit Breakers," July 8, 1988.

5.28 NRC Information Notice 88-46, Supplement 1, "Licensee Report of Defective Refurbished Circuit Breakers," July 21, 1988.

5.29 NRC Information Notice 88-46, Supplement 2, "Licensee Report of Defective Refurbished Circuit Breakers," December 30, 1988.

5.30 NRC Information Notice 88-46, Supplement 3, "Licensee Report of Defective Refurbished Circuit Breakers," June 8, 1989.

5.31 NRC Information Notice 88-46, Supplement 4, "Licensee Report of Defective Refurbished Circuit Breakers," September 11, 1989.

5.32 NUREG/CR-5053, "Operating Experience and Aging Assessment of Motor Control Centers," by W. Shier and M. Subudhi, July 1988.

6. OTHER MANAGEMENT CONSIDERATIONS

6.1 Identification of Effective Management Options to Deal with Action Items Identified in Section 5.4.2

As described in Section 5.4.2, there are several component-specific, service-related, and manufacturer-specific conditions that may require plant-specific activities to establish an effective aging management program for certain MCC components. These conditions and activities are described in the following subsections.

6.1.1 Component-Specific Conditions

- Molded-Case Circuit Breakers. Failures related to molded-case breakers make up the single highest fraction of failures noted in MCC components. Several diagnostic techniques (such as overcurrent trip and pole resistance testing) are used at many plants to evaluate the performance of molded-case breakers. Some plants perform less rigorous testing of their molded case breakers than others. Based on review of the conditions identified in NPRDS, LER, and other historical performance data, the testing methods identified in Section 5.2.2 of this guideline are effective at identifying failed breakers and subcomponents. Additionally, periodic cycling of breaker mechanisms (in accordance with specific plant procedures) may also help preclude instances of breakers failing to operate. Ideally, however, testing methods could also identify breakers that are merely degraded (i.e., that have not yet failed but are less than optimum operating condition), thereby allowing monitoring and replacement prior to in-service failure. At present, the capability to detect these breakers appears limited. This observation is reinforced by the fact that approximately 39% of all failures (NPRDS) related to molded-case breakers were detected during operations. Incipient failure of a breaker cannot, in general, be accurately predicted; hence, MCCB failures that have not been either detected by maintenance/testing or precluded by periodic cycling may adversely impact the required function of the connected load.

- Breaker Operating Handles/Linkages. Of the nearly 400 MCCB failures noted in this study, a substantial portion (i.e., approximately 18% of MCCB-related failures or 7% of all failure reports) were related to the breaker operating handle/linkage. Based on this observation, current maintenance procedures do not appear to completely address the aging mechanisms associated with these types of failures. Failure of the external operating handle could adversely affect the required function of the associated load during normal or accident conditions.

- Starter/Contactor Mechanical Assemblies. The industry failure data presented in Section 3.6 indicate that current maintenance procedures may not be fully effective at mitigating failures of starter/contactor mechanisms (including the main contactor, interlock, and auxiliary contact assemblies). As previously noted, failures of the auxiliary contact assemblies were especially prevalent, constituting 22% of the failures associated with starters/contactors, and 7% of all failures in general. Failure of any of these starter/contactor mechanisms could adversely impact the required function of the associated load.

Based on these observations, nuclear plant operators experiencing substantial rates of in-service molded-case breaker, external operating handle, or starter/contactor mechanism failure should consider implementing the following actions:

1. Review and evaluate the adequacy of existing MCC maintenance and testing programs with respect to manufacturers' and industry guidance and the criteria described in Section 5 of this guideline.

2. If existing maintenance and testing methodology appears to be adequate, then conduct further analysis of MCC component failures to determine if any significant trends exist with respect to individual manufacturers' equipment (i.e., a substantial percentage of failures are related to components of one manufacturer/type) or failure modes (such that a disproportionate number of failures are attributable to a given failure mode). If existing maintenance and testing methodology is not adequately prescribed, upgrade programs/procedures as necessary.

3. If significant component failure trends are noted, conduct a root-cause evaluation to identify the problematic subcomponent, environmental influence, and/or operating condition. (Note: Maintenance/testing programs that have recently been instituted or modified may produce failure trends that are not totally indicative of actual component performance. For example, a given model of breaker may not have been tested prior to the implementation of a current testing program; therefore, the detection of numerous degraded or failed breakers at the outset of the program may not be considered unusual or indicative of any specific trend. However, continued detection of a significant number of failures within the population is cause for concern.)

In addition, the testing frequency of potentially problematic components may be varied to provide some additional assurance of functionality. Testing schedules can be adjusted to test more of the critical components (or a greater proportion of a specific type or manufacturer of component) during each maintenance cycle. For example, a plant that has identified a disproportionate failure rate for a given model of breaker may consider adding more of these breakers to the list of equipment tested during each cycle; this will provide an increased rate of testing with respect to other MCCBs and therefore a greater probability of detection of failed units before required plant functions are affected. Alternatively, if manufacturer or model-specific problems are identified, replacement with other manufacturers' models not subject to the same problem may be warranted.

6.1.2 Service-Related Conditions

- MCCs Exposed to Temperatures in Excess of 40°C [104°F]. MCCs in a limited number of plants can be exposed to temperatures in excess of 40°C [104°F] for significant periods of the day for long periods during the year. The periodicity of the maintenance and surveillance procedures for these MCCs should be frequent enough to ensure that materials potentially susceptible to the effects of elevated temperature (e.g., insulations, organic structural components, lubricants, etc.) are inspected and tested or replaced often enough to preclude failure or severe degradation because of temperature effects. Adequate frequency will be dictated by the severity of the environment and the plant's operating and maintenance experience with these components. For example, MCC components exposed to temperatures only slightly above 40°C [104°F] that have no plant history of failure/rapid degradation may require no increase in maintenance/surveillance frequency (as compared to other MCCs not exposed to elevated temperatures), whereas those operating in temperatures significantly above 40°C [104°F] and that have a demonstrated propensity for rapid degradation may require much more frequent inspection, maintenance, or testing to preclude operational failure.

- MCCs Requiring Qualification for Accident Environments. MCCs that may be exposed to accident environments must be qualified for the accident environment. Environmental qualification programs generally require qualified lives to be established for components based on aging analyses or aging tests. For such MCCs, plant-unique replacement schedules for MCC subcomponents based on the environmental qualification results must be followed. Therefore, the plant programs for these MCCs should incorporate the maintenance concepts described in Section 5.2 and Table 5-1, coupled with the replacement schedule dictated by the qualification program.

- MCCs with High Cycle Operation. Certain components within a given MCC may accumulate much higher numbers of operating cycles than other components because of the operating environment and type of load served. In general, the design cyclic rating for MCC components will vary significantly based on the function of the component. For example, contactor assemblies may be designed for hundreds of thousands of cycles; MCCBs, on the other hand, may be designed for only a few thousand operations. In most cases, operational cycling falls well within component design capabilities. For some MCC components (such as molded-case breakers), operational endurance capabilities or design cyclic lifetimes may be available from applicable equipment standards or directly from the component manufacturer (see Reference 6.1). Plant operators may therefore wish to identify those applications where MCC components are cycled on a frequent basis (i.e., on the order of several times per day on a regular basis); further evaluation of these components (specifically with regard to their failure history) can then be made to determine if more frequent or comprehensive maintenance is appropriate. If little or no corrective maintenance has been necessary between scheduled maintenances for the higher cycle applications, use of the standard maintenance periodicity and practices for the equipment is probably appropriate. It should also be noted that very few safety-related loads are operated/cycled with sufficient frequency to require this type of analysis; however, when coupled with other extrinsic influences (such as dust/dirt contamination, temperature, and/or humidity), components may degrade rapidly prior to reaching their design lifetime.[6.2, 6.3, 6.4, 6.5]

6.1.3 Manufacturer-Specific Conditions

Section 5.4.2 of this guideline identifies the following potential manufacturer-specific concerns based on the historical industry data presented in Section 3.6.

- Gould/ITE MCCBs may fail at a rate well in excess of that of other Gould/ITE components within the same MCC.
- The auxiliary contacts associated with General Electric starter/contactor assemblies may experience a proportionately high number of failures in relation to other General Electric MCC components.

Nuclear plant operators having these MCC should perform the following activities.

- Review the plant failure records for the MCC and its components to determine if such failures are occurring at the plant.
- If a significant number of failures are identified, review the maintenance/surveillance procedures for the equipment to determine if the maintenance/surveillance activities for the subcomponents are sufficiently detailed and frequent to identify and correct problems of the type noted. Upgrade the procedures as appropriate.

Even if no failures of these components are identified, it may be appropriate to review the applicable procedures to ensure that maintenance is of sufficient scope and depth to preclude occurrences.

6.2 Additional Considerations for MCC Maintenance

Because of the substantial cost and effort associated with maintaining nuclear plant electrical equipment, extension of the interval between periodic maintenance activities is desirable. However, before such an extension can be made, a technical justification for the extension should be developed. Factors to be considered in the extension of maintenance periods include the added cost of the study and evaluation necessary to justify the extension, the benefit associated with the extension (in terms of parts/labor saved and possible increases in equipment performance), and the potential for reduced reliability.

It is difficult to develop reliability data and a meaningful mean time between failure for electrical components of the type used in MCCs using the NPRDS and LER data found in this report. Therefore, development of a statistically justifiable periodicity for MCC/component maintenance is not possible based on this information. However, several types of information related to MCC aging and failure can be evaluated, which, when taken collectively, may provide a suitable basis for the judicious extension of equipment maintenance and component replacement intervals. These factors are briefly described in the following paragraphs.

6.2.1 "As-Found" Equipment Condition

An important factor in the determination of the efficacy of existing maintenance practices is the use of component condition information derived from maintenance activities. MCC maintenance represents an important opportunity for collecting information on the actual physical condition of components. By observing and recording the conditions of various components, evaluations of the sufficiency of the current maintenance periodicity and practices can be made more precisely. For example, significant wear of an MCC component detected during maintenance may indicate that the current interval specified should not be lengthened (at least with respect to this component). Conversely, little or no evidence of wear or other degradation may indicate that an extension of the interval is acceptable. "As-found" condition data may also be useful in the determination of periodic component replacement. Information concerning the as-found condition of MCC components can be readily gathered during scheduled maintenance periods (for example, using prepared data sheets listing each significant subcomponent and the possible range of observed conditions), and can be compared with previous data for that same equipment (or data taken from other equipment of the same class) to identify trends and potential problem components.

6.2.2 Equipment Environment

Review of the historical data (contained in Section 3.6) suggests that the environment to which the MCC is exposed may be an important determinant in the rate of degradation of various components. The specific environment in which the equipment operates should be characterized in terms of such factors as temperature, humidity, and contaminants, and accordingly factored into the determination of the appropriate maintenance intervals if it is determined to present significant opportunity for component degradation. Benign environments would indicate the potential for lengthening periods. High temperature, humidity, or contaminant levels would tend to indicate a shorter periodicity.

6.2.3 Plant Maintenance Organization Input

Discussions with plant maintenance personnel can provide valuable insight into the problems and deficiencies encountered with the equipment during normal operations as well as during maintenance. Although much of the relevant history of a given MCC or component may be recorded in one form or another, plant personnel familiar with the maintenance of the equipment may be aware of conditions or problems that are not readily identifiable from databases or other documentation. Unless explicit descriptions of component condition have been recorded during prior maintenance, the only method of recalling this information is through personnel actually associated with maintaining the equipment. So-called "corporate knowledge" of the deficiencies or better-than-expected condition of plant MCCs may provide additional valuable information not otherwise available to the maintenance planner as input for changing the maintenance interval.

6.2.4 Plant-Specific Failure Data

Plant-specific failure data provide important empirical information with regard to the failures actually experienced by the plant equipment. This information is especially significant as the effects of environment, maintenance practices, operations, and any other external influences are present in the failure data. To effectively use these data, it is necessary to separate those events that have caused a failure of an MCC component to fulfill its required function (or would have caused the component to fail had the deficiency not been detected prior to operation) from those induced by maintenance or having no real effect on the operation of the equipment. The net result of this process can be used to estimate the relative failure rate of MCC components and identify potentially problematic devices. The absence of a significant number of component failures would also support increasing the length of the period between maintenances. It should be noted that this type of estimate does not generally allow statistical inferences to be made because of the small population size and other limitations inherent in the data.

6.2.5 Conclusions

Although no one factor described above will in itself constitute a sufficient basis for extension of a maintenance interval, consideration of each of these factors may collectively provide adequate justification. Obviously, more weight should be given to those elements derived from plant-specific information (such as "as-found" condition reports) as opposed to generic industry-wide data. The more completely the aging mechanisms and failure modes of individual MCC components can be described and understood, the more confidently maintenance planners will be able to determine the appropriate component maintenance and replacement schedules for their equipment. Accordingly, data that are consistently recorded and specifically focused on items related to aging and degradation will be extremely beneficial in this process.

6.3 References

6.1 NEMA Standard AB 1-1975 (R 1981), "Molded-Case Circuit Breakers."

6.2 NUREG/CR-5053, "Operating Experience and Aging Assessment of Motor Control Centers," by W. Shier and M. Subudhi, July 1988.

6.3 Wyle Laboratories, "Comprehensive Aging Assessment of Circuit Breakers and Relays for Nuclear Plant Aging Research Program, Phase II."

6.4 NUREG/CR-4715, BNL-NUREG-52017, "An Aging Assessment of Relays and Circuit Breakers and System Interactions," prepared by Franklin Research Center, June 1987.

6.5 Power Plant Electrical Reference Series - Volume 7, "Auxiliary Electrical Equipment," prepared by R.G. Brunner for the Electric Power Research Institute.

APPENDIX A
DEFINITIONS[1]

accelerated aging artificial aging in which the simulation of natural aging approximates, in a short time, the aging effects of longer-term service conditions

acceptance criterion specified limit of a functional or condition indicator used to assess the ability of an SSC* to perform its design function

age (noun) time from fabrication of an SSC to a stated time

age conditioning simulation of natural aging effects in an SSC by the application of any combination of artificial and natural aging

age-related degradation synonym for **aging degradation**

aging (noun) general process in which characteristics of an SSC gradually change with time or use

aging assessment evaluation of appropriate information for determining the effects of aging on the current and future ability of SSCs to function within acceptance criteria

aging degradation aging effects that could impair the ability of an SSC to function within acceptance criteria

aging effects net changes in characteristics of an SSC that occur with time or use and are due to aging mechanisms

aging management engineering, operations, and maintenance actions to control within acceptable limits aging degradation and wearout of SSCs

aging mechanism specific process that gradually changes characteristics of an SSC with time or use

artificial aging simulation of natural aging effects on SSCs by application of stressors representing plant pre-service and service conditions, but perhaps different in intensity, duration, and manner of application

breakdown synonym for **complete failure**

characteristic property or attribute of an SSC (such as shape, dimension, weight, condition indicator, functional indicator, performance or mechanical, chemical, or electrical property)

---

* SSC = system, structure, or component

combined effects net changes in characteristics of an SSC produced by two or more stressors

common cause failure two or more failures due to a single cause

common mode failure two or more failures in the same manner or mode due to a single cause

complete failure failure in which there is complete loss of function

condition the state or level of characteristics of an SSC that can affect its ability to perform a design function

condition surrounding physical state or influence that can affect an SSC

condition indicator characteristic that can be observed, measured, or trended to infer or directly indicate the current and future ability of an SSC to function within acceptance criteria

condition monitoring observation, measurement, or trending of condition or functional indicators with respect to some independent parameter (usually time or cycles) to indicate the current and future ability of an SSC to function within acceptance criteria

condition trending synonym for **condition monitoring**

corrective maintenance actions that restore, by repair, overhaul, or replacement, the capability of a failed SSC to function within acceptance criteria

degradation immediate or gradual deterioration of characteristics of an SSC that could impair its ability to function within acceptance criteria

degraded condition marginally acceptable condition of an unfailed SSC that could lead to a decision to perform planned maintenance

degraded failure failure in which a functional indicator does not meet an acceptance criterion, but design function is not completely lost

design basis conditions synonym for **design conditions**

design basis event any of the events specified in the station's safety analysis that are used to establish acceptable performance for safety-related functions of SSCs; events include anticipated transients, design basis accidents, external events, and natural phenomena

design basis event conditions service conditions produced by design basis events

design basis event stressor stressor that stems from design basis events and can produce immediate or aging degradation beyond that produced by normal stressors

design conditions specified service conditions used to establish the specifications of an SSC (generally includes margin of conservatism beyond expected service conditions)

design life period during which an SSC is expected to function within acceptance criteria

design service conditions synonym for **design conditions**

deterioration synonym for **degradation**

diagnosis examination and evaluation of data to determine either the condition of an SSC or the causes of the condition

diagnostic evaluation synonym for **diagnosis**

environmental conditions ambient physical states surrounding an SSC

error-induced aging degradation aging degradation produced by error-induced conditions

error-induced conditions adverse pre-service or service conditions produced by design, fabrication, installation, operation, or maintenance errors

error-induced stressor stressor that stems from error-induced conditions and can produce immediate or aging degradation beyond that produced by normal stressors

failure inability or interruption of ability of an SSC to function within acceptance criteria

failure analysis systematic process of determining and documenting the mode, mechanism, causes, and root cause of failure of an SSC

failure cause circumstances during design, manufacture, test, or use that have led to failure

failure evaluation synonym for **failure analysis**

failure mechanism physical process that results in failure

failure mode the manner or state in which an SSC fails

failure modes and effects analysis systematic process for determining and documenting potential failure modes and their effects on SSCs

failure trending recording, analyzing, and extrapolating in-service failures on an SSC with respect to some independent parameter (usually time or cycles)

functional conditions influences on an SSC resulting from the performance of design functions (operation of a system or component and loading of a structure)

functional indicator condition indicator that is a direct indication of the current ability of an SSC to function within acceptance criteria

inservice inspection methods and actions for assuring the structural and pressure-retaining integrity of safety-related nuclear power plant components in accordance with the rules of this Section [ASME Code, Section XI]

inservice life synonym for **service life**, (especially in discussions involving ASME Code Section XI)

inservice test a test to determine the operational readiness of a component or system [ASME Code, Section XI]

inspection synonym for **surveillance**

installed life period from installation to retirement of an SSC

life period from fabrication to retirement of an SSC

life assessment synonym for **aging assessment**

life cycle management synonym for **life management**

life management integration of aging management and economic planning to: (1) optimize the operation, maintenance, and useful life of SSCs; (2) maintain an acceptable level of performance and safety; and (3) maximize return on investment over the useful life of the plant

lifetime synonym for **life**

maintenance aggregate of direct and supporting actions that detect, preclude, or mitigate degradation of a functioning SSC, or restore to an acceptable level the design functions of a failed SSC

malfunction synonym for **failure**

mean time between failures arithmetic average of operating times between failures of an item [IEEE Std 100]

natural aging aging of an SSC that occurs under pre-service and service conditions, including error-induced conditions

normal aging natural aging from error-free pre-service or service conditions

normal aging degradation aging degradation produced by normal conditions

normal conditions operating conditions of a properly designed, fabricated, installed, operated and maintained SSC excluding design basis event conditions

normal operating conditions synonym for **normal conditions**

normal stressor stressor that stems from normal conditions and can produce aging mechanisms and effects in an SSC

operating conditions service conditions, including normal and error-induced conditions, prior to the start of a design basis accident or earthquake

operating service conditions synonym for **operating conditions**

operational conditions synonym for **functional conditions**

overhaul (noun) extensive repair, refurbishment, or both

performance indicator synonym for **functional indicator**

periodic maintenance form of preventive maintenance consisting of servicing, parts replacement, surveillance, or testing at predetermined intervals of calendar time, operating time, or number of cycles

planned maintenance form of preventive maintenance consisting of refurbishment or replacement that is scheduled and performed prior to failure of an SSC

post-maintenance testing testing after maintenance to verify that maintenance was performed correctly and that the SSC can function within acceptance criteria

preconditioning synonym for **age conditioning**

predictive maintenance form of preventive maintenance performed continuously or at intervals governed by observed condition to monitor, diagnose, or trend an SSC's functional or condition indicators; results indicate current and future functional ability or the nature and schedule for planned maintenance

premature aging aging effects of an SSC that occur earlier than expected because of errors or pre-service and service conditions not considered explicitly in design

pre-service conditions actual physical states or influences on an SSC prior to initial operation (e.g., fabrication, storage, transportation, installation, and pre-operational testing)

preventive maintenance actions that detect, preclude, or mitigate degradation of a functional SSC to sustain or extend its useful life by controlling degradation and failures to an acceptable level; there are three types of preventive maintenance: periodic, predictive, and planned.

qualified life period for which an SSC has been demonstrated, through testing, analysis, or experience, to be capable of functioning within acceptance criteria during specified operating conditions while retaining the ability to perform its safety functions in a design basis accident or earthquake

random failure any failure whose cause or mechanism, or both, make its time of occurrence unpredictable [IEEE Std 100]

reconditioning synonym for **overhaul**

refurbishment planned actions to improve the condition of an unfailed SSC

remaining design life period from a stated time to planned retirement of an SSC

remaining life actual period from a stated time to retirement of an SSC

remaining service life synonym for **remaining life**

remaining useful life synonym for **remaining life**

repair actions to return a failed SSC to an acceptable condition

replacement removal of an undegraded, degraded, or failed SSC or a part thereof and installation of another in its place that can function within the original acceptance criteria

residual life synonym for **remaining life**

retirement final withdrawal from service of an SSC

rework correction of inadequately performed fabrication, installation, or maintenance

root cause fundamental reason(s) for an observed condition of an SSC that if corrected prevents recurrence of the condition

root cause analysis synonym for **failure analysis**

service conditions actual physical states or influences during the service life of an SSC, including operating conditions (normal and error-induced), design basis event conditions, and post design basis event conditions

service life actual period from initial operation to retirement of an SSC

servicing routine actions (including cleaning, adjustment, calibration, and replacement of consumable) that sustain or extend the useful life of an SSC

simultaneous effects combined effects from stressors acting simultaneously

stress synonym for **stressor**

stressor agent or stimulus that stems from pre-service and service conditions and can produce immediate or aging degradation of an SSC

surveillance observation or measurement of condition or functional indicators to verify that an SSC currently can function within acceptance criteria

surveillance requirements test, calibration, or inspection to assure that the necessary quality of systems and components is maintained, that facility operation will be within the safety limits, and that the limiting conditions of operation will be met [10 CFR 50.36] (for use only when specific regulatory and legal connotations are called for)

surveillance testing synonym for **surveillance, surveillance requirements**, and **testing** (use only when specific regulatory and legal connotations are called for)

synergistic effects portion of changes in characteristics of an SSC produced solely by the interaction of stressors acting simultaneously, as distinguished from changes produced by superposition from each stressor acting independently

testing observation or measurement of condition indicators under controlled conditions to verify that an SSC currently conforms to acceptance criteria

time in service time from initial operation of an SSC to a stated time

useful life synonym for **service life**

wearout failure produced by an aging mechanism

Relationship of Aging Terms

A **stressor**, produces by such conditions as temperature, radiation, or voltage, acts on a component. If the component (or its materials) is sensitive to the stressor, an **aging mechanism** will occur.

An **aging mechanism** may lead to **age-related degradation** if the effects of the aging mechanisms that result in age-related degradation are not accounted for through such actions as maintenance.

Eventually, an aging mechanism may lead to a **failure mechanism**. The result of the failure mechanism is the **failure mode** of the component.

Review of the failure mode, failure and aging mechanisms, age-related degradation, and stressors will provide the **failure cause** for age-related failures.

References

1. EPRI TR-100844, "Nuclear Power Plant Common Aging Terminology," prepared by MPR Associates, Inc., November 1992.

APPENDIX B
DOCUMENTS NOT RELATED TO EQUIPMENT AGING

Table B-1 lists those Information Bulletins, Circulars, and Notices that were determined to be unrelated to aging degradation of motor control centers. A justification for designing these Bulletins, Circulars, and Notices as unrelated to motor control center aging degradation is provided.

Table B-1. Bulletins, Circulars, and Notices Not Related to Motor Control Center Aging Degradation

Document/Title/Date	Justification
Bulletin 74-13, "Improper Factory Wiring on General Electric Motor Control Centers at Fort Calhoun"	Defective wire terminations caused by improper factory wiring practices of the breaker/starters
Bulletin 74-15, "Misapplication of Cutler-Hammer Three Position Maintained Switch Model 10250T"	Misapplication of three position switch in diesel control panels
IE Circular 76-02, "Relay Failures-Westinghouse BF (ac) and BFD (dc) Relays"	Manufacturing defect; internal component rubbing (pin)
IE Bulletin 78-01, "Flammable Contact-Arm Retainers in G.E. CR120A Relays"	Retainer was made from flammable material and changed to a flame resistant material; no generic overheating
IE Bulletin 78-05, "Malfunctioning of Circuit Breaker Auxiliary Contact Mechanism - General Electric Model CR105X"	Potential binding problem with auxiliary interlocks mounted on contactors, starters, or reversers; generic problem; replacement recommended
IE Circular 78-09, "Arcing of General Electric Size 2 Contactors"	Manufacturing defect caused by oversized copper tip support bindings causing binding and arcing
IE Circular 79-23, "Motor Starters and Contactors Failed to Operate"	Faulty units caused by undersized dimensions of support legs; manufacturing deficiency
IE Information Notice 84-78, "Underrated Terminal Blocks That May Adversely Affect Operation of Essential Electric Equipment"	Deficiency concerning underrated motor terminal blocks by manufacturers that could result in electrical shorting

Table B-1. Bulletins, Circulars, and Notices Not Related to Motor Control Center Aging Degradation (continued)

Document/Title/Date	Justification
NRC Information Notice 85-16, "Time/Current Trip Curve Discrepancy of ITE/Siemens-Allis Molded-Case Circuit Breaker"	Actuation point of magnetic trip element substantially higher than time-current curve; incorrect curve
IE Information Notice 85-49, "Relay Calibration Problem"	Inadequate relay calibration procedure
NRC Information Notice 86-62, "Potential Problems in Westinghouse Molded-Case Circuit Breakers Equipped with a Shunt Trip"	Manufacturing defect; excessive material in operating handle may cause continuous energization of shunt trip coil
IE Information Notice 86-66, "Potential for Failure of Replacement AC Coils Supplied by the Westinghouse Electric Corporation for Use in Class 1E Motor Starters and Contactors"	Manufacturer's production of defective coils between June 1, 1984, and December 31, 1985
NRC Information Notice 88-45, "Problems in Protective Relay and Circuit Breaker Coordination"	Lack of proper circuit breaker and protective relay coordination
NRC Information Notice 90-43, "Mechanical Interface with Thermal Trip Function in GE Molded-Case Circuit Breakers"	Manufacturing defect; improper installation of calibration screw spring clips on thermal trip element
Information Notice 92-24, "Distributor Modification to Certain Commercial Grade Agastat Electrical Relays"	Alteration of nameplate labels and modification of relay
NRC Information Notice 92-51, "Misapplication and Inadequate Testing of Molded Case Circuit Breakers"	Improper analysis, selection, and postinstallation testing of breaker is a design consideration and does not address aging

APPENDIX C
ACRONYMS

A	Ampere
ac	Alternating current
AMG	Aging Management Guideline
ANSI	American National Standards Institute
AWS	American Welding Society
BTP	Branch Technical Position (U.S. NRC)
BWR	Boiling Water Reactor
CFR	Code of Federal Regulations
Class 1E	Class 1 Electrical Equipment (IEEE designation for safety-related)
DBE	Design basis event
dc	Direct current
DG (EDG)	Diesel generator (emergency diesel generator)
DOE	Department of Energy
EPRI	Electric Power Research Institute
FSAR	Final Safety Analysis Report
GDC	General Design Criteria
GE	General Electric
HELB	High-energy-line break
hp	horsepower
ICEA	Insulated Cable Engineers Association
IE	Inspection and Enforcement (former NRC Division)
IEEE	Institute of Electrical and Electronics Engineers
INPO	Institute for Nuclear Plant Operation
IPA	Integrated Plant Assessment
IR	Industry Report
ISM	Inspection, Surveillance, and Monitoring
ITLR	Important to license renewal
kVac	Kilovolts alternating current
LCM	Life Cycle Management
LCO	Limiting Condition for Operation
LER	Licensee Event Report
LOCA	Loss-of-coolant accident
LWR	Light water reactor
MCC	Motor control center

MCCB	Molded-case circuit breaker
MCP	Motor circuit protector
MVA	Megavolt amperes
NEMA	National Electrical Manufacturer's Association
NMAC	Nuclear Maintenance Applications Center
NPAR	Nuclear Plant Aging Research
NPE	Nuclear Power Experience
NPRDS	Nuclear Plant Reliability Data System
NRC	U.S. Nuclear Regulatory Commission
NUMARC	Nuclear Management and Resources Council
PLIM	Plant Lifetime Improvement
PVC	Polyvinyl chloride
PWR	Pressurized water reactor
rd	Rad (unit of radiation)
RG	Regulatory Guide
rm	Root mean square
SCs	Structures and components
SNL	Sandia National Laboratories
SQUG	Seismic Qualification Utility Group
SRP	Standard Review Plan
SSCs	Systems, structures, and components
SSTD	Solid-state trip device
STC	Shunt trip coil
Std	Standard
UL	Underwriter's Laboratories
UVR	Undervoltage release
Vac	Volts alternating current
Vdc	Volts direct current

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