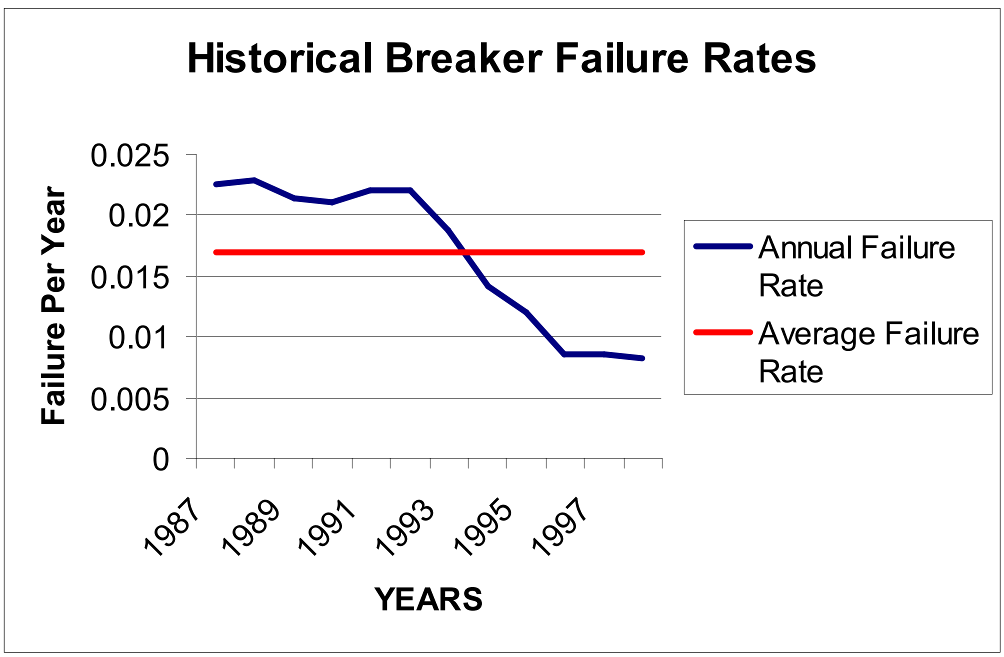
Life Cycle Management Planning Sourcebooks

Volume 7: Low Voltage Electrical Distribution Systems

Technical Report



Life Cycle Management Planning Sourcebooks

Volume 7: Low Voltage Electrical Distribution Systems

1007426

Final Report, February 2003

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This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Life Cycle Management Planning Sourcebooks: Volume 7: Low Voltage Electrical Distribution Systems, EPRI, Palo Alto, CA: 2003. 1007426.

REPORT SUMMARY

EPRI is producing a series of Life Cycle Management Planning Sourcebooks, each containing a compilation of industry experience information and data on aging degradation and historical performance for a specific type of system, structure, or component (SSC). This sourcebook provides information and guidance for implementing cost-effective life cycle management (LCM) planning for low voltage electrical distribution systems.

Background

As explained in the *LCM Sourcebook Overview Report* (1003058), the industry cost for producing LCM plans for many of the important SSCs in operating plants can be reduced if LCM planners have an LCM sourcebook of generic industry performance data for each SSC they address. The general objective of EPRI's LCM sourcebook effort is to provide system engineers with generic information, data, and guidance they can use to generate a long-term equipment reliability plan for the plant-specific SSC (aging and obsolescence management plans optimized in terms of plant performance and financial risk). The long-term equipment reliability plan, or "LCM plan," for a plant SSC combines industry experience and plant-specific performance data to provide an optimum maintenance plan, schedule, and cost profile throughout the plant's remaining operating life.

Objective

The objective of this LCM sourcebook is to provide plant engineers (or their expert consultants) with a compilation of the generic information, data, and guidance typically needed to produce a plant-specific LCM plan for low voltage electrical distribution systems.

Approach

Experts in the maintenance and aging management of low voltage distribution systems followed the LCM process developed in EPRI's *LCM Implementation Demonstration Project* (1000806). The scope of the physical system and types of components included in the study was defined. Information and data on historical industry performance of components within this scope were compiled and technical guidance for using this information is presented as a starting point for preparing plant-specific low voltage distribution system LCM plans. The sourcebook was reviewed by EPRI LCM utility advisors prior to its publication.

Results

This sourcebook contains information on Low Voltage Distribution Systems (LVDS) and particularly their associated circuit breakers. Information compiled includes performance monitoring issues, component aging mechanisms, aging management maintenance activities, equipment upgrades, replacements, and, most importantly, technical obsolescence assessments.

The sourcebook includes an extensive list of references, many of which are EPRI reports related to the maintenance and reliability of circuit breakers.

EPRI Perspective

This report should enable the preparation of plant-specific LCM plans for low voltage electrical distribution systems with substantially less effort and cost than if planners had to start from scratch. The sourcebook captures both industry experience and the expertise of the sourcebook authors. Using this sourcebook, one needs only to add plant-specific data and information to complete an economic evaluation and LCM plan for the plant's low voltage electrical distribution system. EPRI plans to sponsor additional LCM sourcebooks for as many important SSC types as may be useful to operating plants (perhaps 30 to 40) and as are allowed by industry-wide resources. The process of using sourcebooks as an aid in preparing LCM plans will improve as the industry gains experience. EPRI welcomes constructive feedback from users and plans to incorporate lessons learned in future revisions of LCM sourcebooks.

Keywords

Life cycle management
Nuclear asset management
System reliability
Component reliability
Circuit breakers

ACKNOWLEDGEMENTS

The technical contribution, review, and comment by the following individuals are greatly appreciated:

Paul Colaianni, Duke Energy

Maurice Dingler, Wolf Creek

Craig Irish, NLI

Dan Lehnert, LCMT

Ken Petroff, PSEG

Jim Sharkey, EPRI Charlotte

Ken Wolfe, Consultant

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MANAGEMENT SUMMARY

This Life Cycle Management (LCM) Planning Sourcebook for Low Voltage Distribution Systems (LVDS) will help guide your plant engineers or expert consultant in preparing a life cycle management plan (long-term reliability plan) for the plant-specific LVDS components. The generic information and guidance presented in the sourcebook is expected to help plant engineers focus on areas where there may be significant opportunities for cost-effective improvements in long-term plans. Also, it may reduce the cost of preparing a plant-specific LCM plan for LVDS by about a third compared to starting from scratch.

Guidance consists mainly of generic information, data, and references; industry-wide LDVS and specifically breaker issues and ways to ensure that they are addressed at your plant; LVDS component aging mechanisms together with the maintenance activities to manage them; breaker obsolescence issues and available management options; and alternative LCM plans that can be considered during long-term planning for the LVDS critical components. This sourcebook provides a hypothetical LCM plan to illustrate plant-specific application. Depending on the level of detail desired for the plant-specific LCM plan, the generic data in this sourcebook may allow engineers to identify areas where significant cost-effective improvements or reduction in onerous maintenance activity can be realized and long term planning for emerging obsolescence issues can be developed.

Important reasons for covering LVDS components in a sourcebook are that (1) high reliability of the 480 VAC and 125/250 Volt AC/DC systems is important to economic plant operation, (2) at most plants, relatively little attention is paid to inspection and maintenance of non-safety LVDS components, and (3) most of the critical components within the LVDS will become obsolete within the next ten years, requiring replacement, substitution or technological upgrades, particularly for plants contemplating license renewal.

LVDS component industry reliability issues identified by this study are:

- Breakers represent more than 94% of all LVDS failures, as reported in EPIX
- Many breaker problems emanate from design, fabrication and assembly errors or misapplication of the breakers.
- Aging and maintenance of grease and lubricants requires close attention

The technical obsolescence issues for the LVDS components are:

- MCCBs have a limited life and most models currently in use are no longer available on the market. 480 Volt breakers are also approaching obsolescence problems, however, overhaul kits are still available for most.

The potential alternative LCM plans to be considered include:

- Implementation of diagnostic programs (thermography) and fine tuning of PM procedures.
- Consideration of time directed periodic overhauls of 480-volt breakers.
- Various replacement options, using like-for-like replacements, replacement with a new model or different vendor, or replacement with a new technology (solid state, digital control).
- Consideration of the more recent option of “Modular Replacement”, including complete buckets or MCCs.

2
LCM SOURCEBOOK INTRODUCTION

2.1 Purpose of LCM Sourcebook

This Low Voltage Distribution System (LVDS) LCM Sourcebook is a compilation of the generic information, data, and guidance an engineer typically needs to produce a plant-specific LCM plan for a LVDS and its principal components, specifically breakers. The engineer need only add plant-specific data and information to complete an economic evaluation and LCM plan for the LVDS. It must be recognized that not all generic information in a sourcebook applies to every plant. However, its applicability may be determined by benchmarking the generic data against plant-specific experience. The data may also show indicators or precursors to problems not yet experienced at a given plant. Caution and guidance is therefore provided in the plant-specific guidance sections (Sections 5, 8, and 9) for the use and application of the generic information. These sections also contain useful tips and lessons learned from the EPRI LCM Plant Implementation Demonstration program [1] (which included an evaluation of the Prairie Island 480 Volt Distribution System) and other related plant-specific LCM plans, such as the "Low and Medium Voltage Switchgear (460 VAC to 4KV) LCM Plan" [2] developed by EPRI for PSE&G.

2.2 Relationship of Sourcebook to LCM Process

The process steps for LCM planning are described in detail in the EPRI LCM report [1]. The LCM planning flowchart in Figure 2-1 of this LVDS Sourcebook is the same as Figure 1-1 of the LCM Sourcebook Overview Report [3] and Figure 2-2 of the LCM report [1]. The flowchart was modified only to improve clarity with respect to aging management and technical obsolescence (i.e. Step 11 has been subdivided into three distinct tasks) and to add a color code to explain the contents of the overview report. The chart is segmented into the four elements of the LCM planning process: SSC Categorization/Selection, Technical Evaluation, Economic Evaluation, and Implementation. Process step numbering has been maintained consistent with the LCM report. Color codes in Figure 2-1 identify topics for which generic data are provided by section reference; topics for which plant-specific LCM planning guidance is provided by section reference; and topics not addressed in the Sourcebook

2.3 Basis for Selection of the LVDS for LCM Sourcebook

The LVDS was selected for preparation of a sourcebook by EPRI-member utility advisors. Using an initial listing of important SSCs, the sourcebook candidates were ranked in accordance with the average priority given by LCM Advisory Committee members and considering generic applicability, SSC importance for power production and safety, potential for degradation and obsolescence and concern for maintenance.

The main reasons for the selection of the LVDS were:

- It is applicable to many (or all) plants (BWRs, PWRs, or both)
- It is important to safety risk or a regulatory concern
- It is important to power production
- It is subject to significant degradation or obsolescence
- It has a history of chronic maintenance problems.

Figure 2-1a
LCM Planning Flowchart – SSC Categorization and Selection

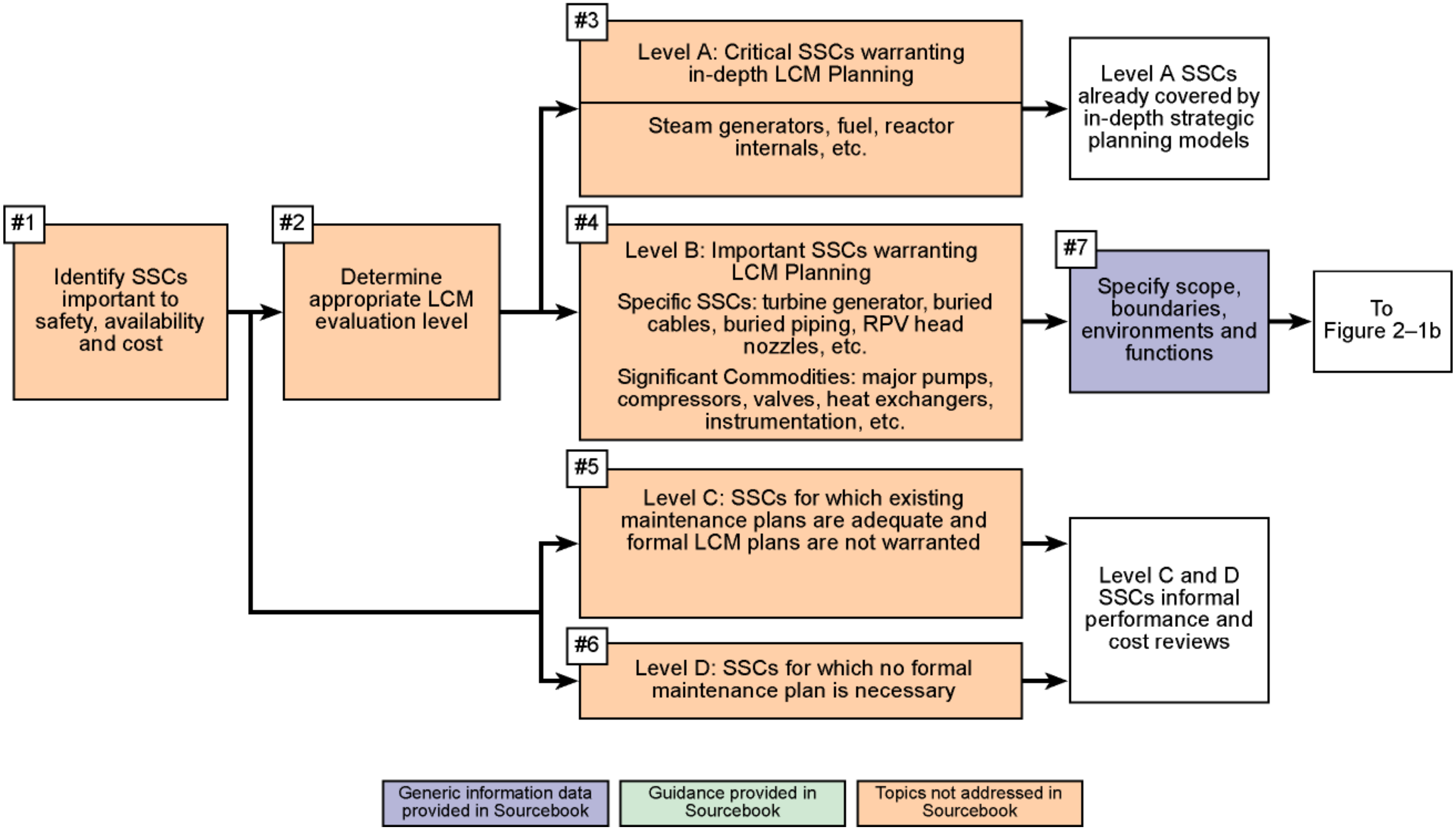


Figure 2-1b
LCM Planning Flowchart – Technical and Economic Evaluation

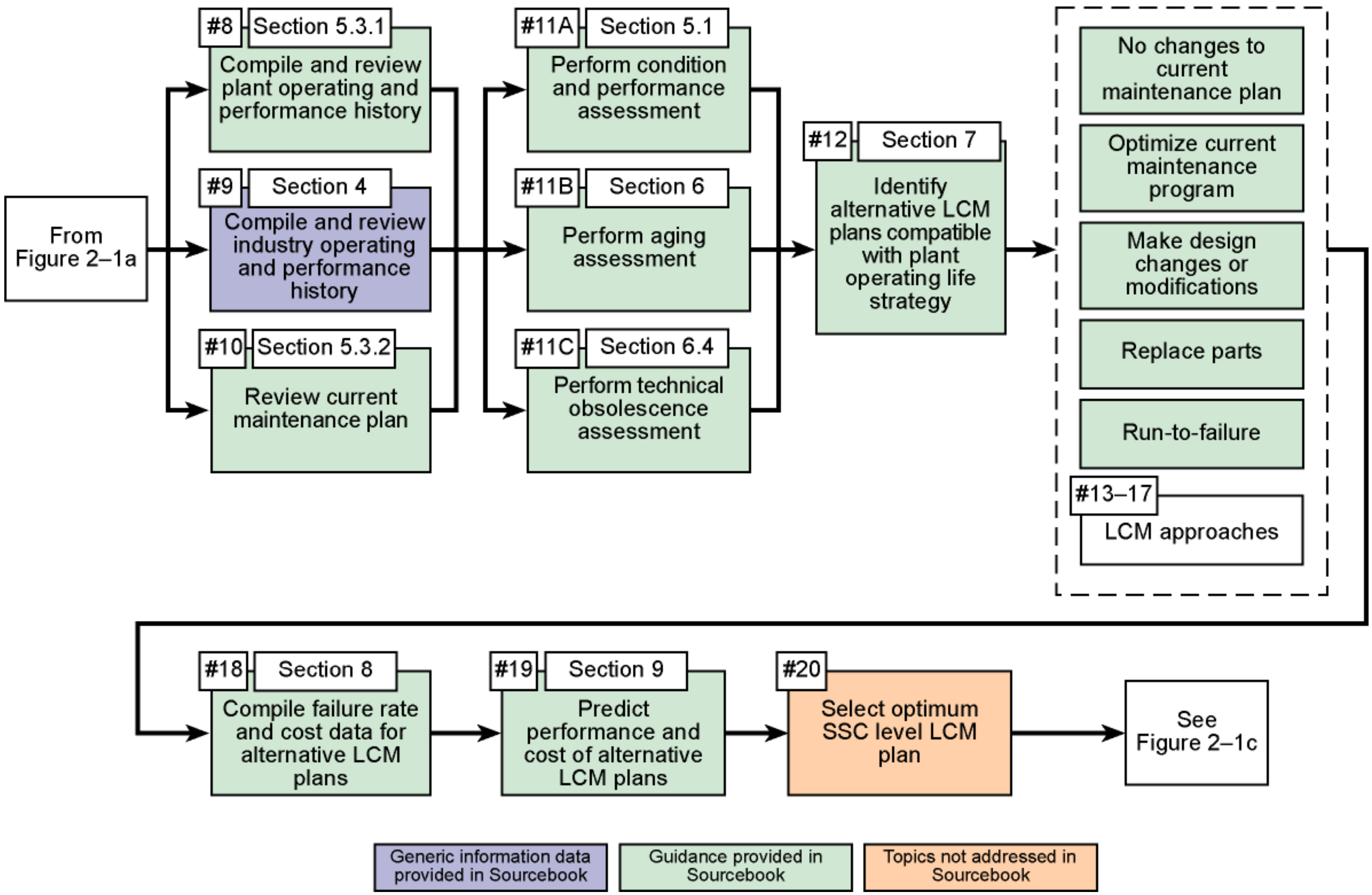
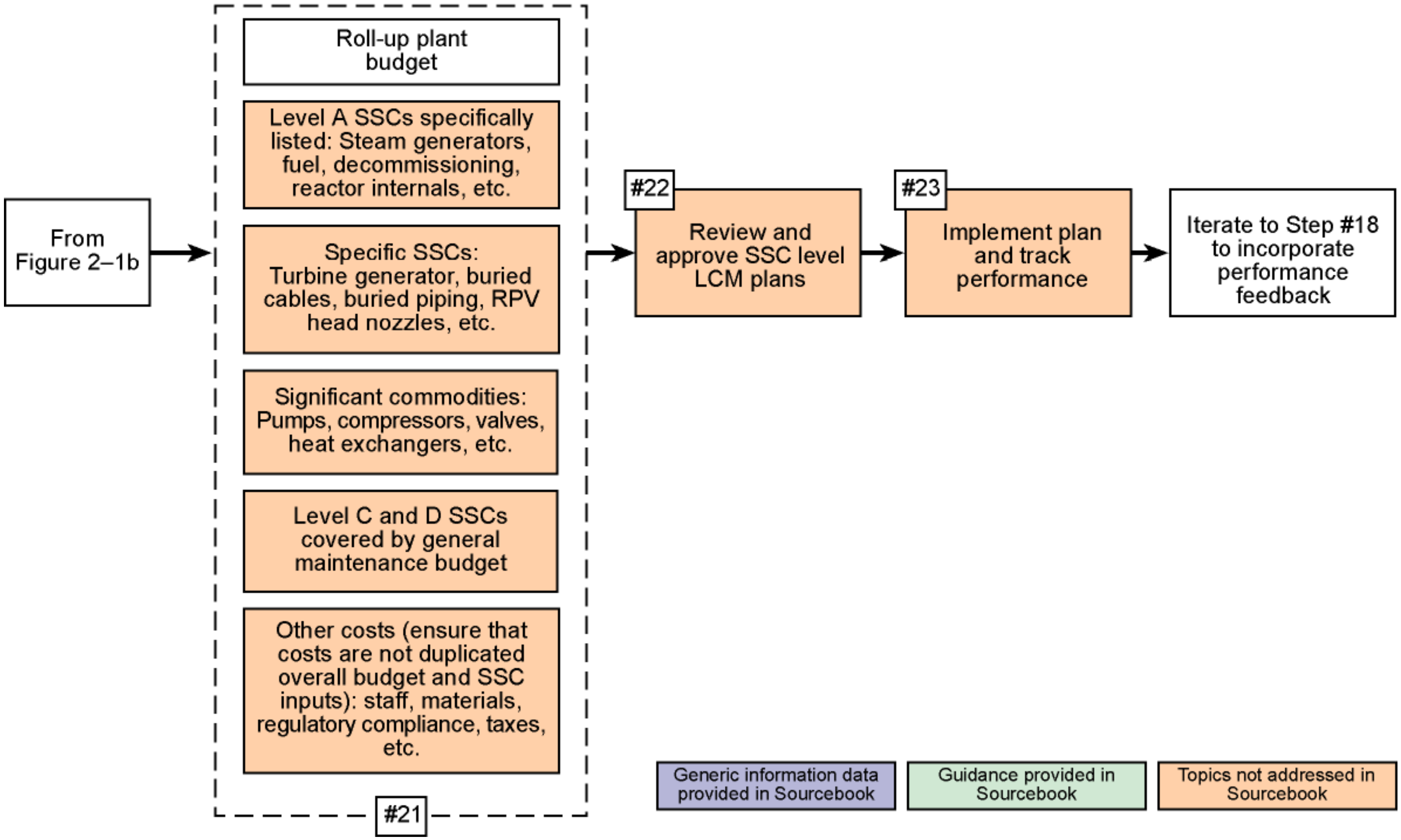


Figure 2-1c
LCM Planning Flowchart – Implementation



3
BASIC INFORMATION ON LVD SYSTEM

This section addresses step number 7 in Fig. 2-1a. The LVDS consists of a number of subsystems and is comprised of the 480 Volt AC system and the 125/250 Volt AC and DC systems. The LVDS function is to provide a highly reliable source of power to low voltage auxiliary equipment and to provide electrical isolation/protection in case of electrical faults or overloads. This equipment may be required during any one of the normal or emergency modes of plant operation. The critical components within the LVDS are very similar in design and function for both BWRs and PWRs and among the individual plants. This Sourcebook is therefore applicable to BWRs and PWRs alike in that the common design, operating conditions and equipment problems can be addressed, with some limitations, by the same set of generic data.

3.1 Safety and Operational Significance

A failure of the off-site power supply will typically result in a plant trip and an automatic start of the Emergency Power Supply (Emergency Diesel Generators [EDGs] or other on-site power systems) to facilitate an orderly shutdown. Likewise, major faults generated within the LVDS can result in the loss of a complete bus and all the loads connected to it, in turn resulting in reduced power operation or a plant trip.

The 480 VAC buses receive their power from the 4160-480V step-down transformers, which, for the safety-related loads, are powered by the Emergency Diesel Generators and onsite 4160 buses. The normal on-site and/or off-site supplied 13 KV-4160V-480V step-down transformers provide the power to non-safety-related 480 VAC buses.

The individual plant arrangement of the buses (4160, 480, 125/250) varies widely, from ring buses and split buses to swing buses to redundant, triple and quadruple supply buses. In general, the safety-related buses have full redundancy and the capability to be powered by the on-site and/or off-site normal power sources and of course the EDGs in case of an emergency or the failure of the normal power supplies. Important non-safety-related loads, but critical to the power generation, are sometimes also supplied by emergency power on a selective basis to prevent equipment damage or to facilitate black start capability.

The LVDSs are typically modeled in the plant's PRA and are often designated as risk significant, dependant on the individual design and redundancy provisions.

Because of its functional importance, the individual components within the distribution systems (such as relays and breakers) are often redundant or feature installed spares to facilitate temporary bypassing of the failed component. Recognizing that the equipment is normally energized during plant operation (except for some standby equipment), maintenance and surveillance testing must be performed during outages or the affected system must be temporarily taken out of service, if possible.

The system is designed such that most individual component failures (specifically breakers) do not render the system inoperable. To cope with breaker failures, an abnormal operating condition is declared, the affected component is isolated, bus sections are temporarily cross connected and the failed component is repaired or replaced after which the system is returned to normal.

3.2 LVDS Functions

The LVDS and its subsystems provide both safety-related and non-safety-related functions including:

- Deliver adequate AC voltage to the motor terminals for motors in the 20 to 300 horsepower range.
- Provide primary and backup over-current protection for the equipment in case a component develops a short circuit or otherwise jeopardizes the functional integrity of the system.
- Provide power to transformers supplying the 125/250 VAC instrument buses, station lighting, battery chargers, UPSs (Uninterruptible power supplies), inverters and other lower voltage services.
- Provide DC voltage to the 125/250 VDC motor terminals, DC instrument buses and annunciator panels and control power for the vital 480 and 4160 VAC buses. The DC power is supplied via 125/250 VAC station batteries.

3.3 LVDS System and Component Boundaries

This sourcebook for the LVDS includes the 480 Volt AC and 125/250 Volt AC and DC distribution systems, including both safety and non-safety-related systems in the plant. The system and component boundary includes Motor Control Centers (MCC), power supply and distribution cabinets and buckets, and the components within (breakers, relays, molded case circuit breakers, transformers, thermal overloads, auxiliary switches, trip coils, fuses, fuse disconnects, contacts, stabs, etc). Also included are buses, rectifiers, inverters and Uninterruptible Power Supplies (UPSs) required for the functions of the 480 VAC and 125/250 VAC/DC systems. Excluded from the scope of this sourcebook are DC batteries and battery chargers, MG-sets and all wiring, cable, and associated termination strips.

The detail and depth of evaluation for the individual components is commensurate with their importance and reliability. Passive components such as small transformers, panels and buckets, buses, fuses, contacts and the like, which are not major contributors to lost power generation or system reliability, are treated as a commodity, while the focus of the LCM Sourcebook is on the critical system components of the LVDS.

The following provides a discussion of the individual components within the LVDS and their respective functions and importance.

A - Active Components

Breakers
The electrical components that comprise the LVDS consist of passive and active components. On the basis of industry experience and failure history accumulated over the last ten years, the active system components of the LVDS, comprised of the breakers (also called circuit breakers, switchgear or low voltage switchgear), including Molded Case Circuit Breakers (MCCBs), represent the most critical components. The quantity (between 500 and 2000 per plant) and diversity of the breakers found in a plant, requires that breaker categories be established based on service, vendor, type/model and obsolescence. Equipment obsolescence of the breakers is a major current concern, as OEM vendors have, or are contemplating, discontinuing manufacture, service and parts supply for the various breakers. The long-term maintenance plans therefore will be driven by the replacement options and technological upgrades.

Trip Units
Another family of important active components in the LVDS consists of the circuit breaker low-voltage trip units. These devices provide the overcurrent and short circuit protection tripping signal to the circuit breakers. Two primary generations of trip units are found depending on the equipment age: electro-mechanical and solid state. Primary cause of failure for electro-mechanical trip units is drift of accuracy and binding of internal moving parts. Solid-state trip unit failure is mostly due to electronic sub-component failure. This failure mode can also cause nuisance tripping. The under-voltage trip units are electro-mechanical devices on older circuit breakers and provide protection by actuating the breaker tripping mechanism in the event of an under-voltage condition. Primary cause of failure is solenoid winding failure. The trip units are typically replaced upon failure or calibration problems. As with the breakers, obsolescence is the major long term maintenance issue with the trip units.

Relays
Relays are primarily electro-mechanical devices used for a broad range of control applications. Primary cause of failure is mechanical failure of the internal mechanism. Relays are typically replaced when failure has occurred and maintenance is minimal or they are considered run-to-failure.

Fuse Disconnects
These devices provide a means for disconnect and for overcurrent/short circuit protection. Primary cause of failure is usually due to spring mechanism and switch blade failure caused by improper lubrication and loose contact.

Motor Starters
These devices function to open and close motor circuits under various operating parameters. The motor starter provides control of the motor operation and overload protection. These functions are electro-mechanical or solid state or both. The contactor element varies in size and type and is generally of an electro-mechanical device. The primary cause of failure is contact erosion due to overheating and excessive current.

B - Passive Components

In general, passive components have caused very few failures and exhibit high reliability and a fairly long life. They are most likely run-to-failure components and are functionally tested (if used in standby service) only at the time the system they serve is energized and tested. The following components are included in this category:

Small Dry Type Transformers
These devices typically provide control power and step down power for small loads. Primary failure is usually due to winding failure caused by overheating and shorts.

Buses
These current carrying conductors, referred to as bus bars and bus ducts, are used in switchgears, motor control centers and similar enclosures. Bus ducts are generally used in lieu of large current carrying capacity power cables. Primary failure is usually due to loose connection overheating or excessive corrosion by abnormal exposure.

Rectifier
The rectifier is a special purpose solid-state device used in the rectification of alternating current to direct current applications. Primary cause of failure is usually due to semiconductor component failure.

Inverters
The inverter is a special purpose solid-state device used in the conversion from direct current to alternating current applications. Primary cause of failure is usually due to semiconductor component failure.

Uninterruptable Power Supplies (UPS)
The UPS utilizes a battery backup system to provide continuous AC power during power failure by inverting direct current to AC, and rectifying AC to DC to recharge batteries. Primary cause of failure is due to semiconductor component failure and battery bank failure.

3.4 Scope of Equipment Covered by the LVDS Sourcebook

The scope of the LCM sourcebook for the LVDS includes the 480 Volt AC and 125/250 Volt AC and DC distribution systems, including both safety and non-safety-related systems in BWR and PWR plants. The focus of the LVDS sourcebook is directed towards the breakers, while the other active and passive components are addressed commensurate with their importance. Maintenance practices, failure data and IOE for these components (if they exist) are provided and summarized.

Table 3-1 provides a listing of the breaker types/models and vendors most represented in the installed breaker population and which are addressed in this sourcebook. The evaluation grouping for the breakers are driven by their obsolescence immediacy and are established as follows:

Obsolescence Category 1: Breakers that are discontinued and for which one-for-one replacements or spare parts have become unavailable.

Obsolescence Category 2: Breakers that have been discontinued but for which parts kits and overhaul service is secure for the next 5 to 10 years.

Obsolescence Category 3: Breakers for which replacements continue to be available for the next 10 to 20 years.

While this sourcebook focuses on the breakers shown in Table 3-1, much of the generic data evaluated included also breaker models and manufacturers other than those listed. The conclusions and recommendations therefore may have limited applicability to those other breaker models.

LVDS components other than breakers were reviewed to determine their importance in LCM planning. Most of the components are essentially run-to-failure and receive maintenance only in conjunction with the breaker or cubicle PM (cleaning, visual inspection). The EPIX database for the 480 Volt system identifies 476 hits for the years 1997 to 2002. Less than 6% of the hits involved components other than breakers and very few of them caused a loss of system function. Only one incident (a transformer failure) resulted in a loss of power generation. In order to devote the resources to the principal problems, these other LVDS components were therefore not further investigated.

Table 3-1
230/480 Volt Breaker List
Note, breakers are grouped according to the obsolescence immediacy

Breaker Vendors	Breaker Models	Obsolescence Category 1	Obsolescence Category 2	Obsolescence Category 3
ITE-Gould	KB/RH, BQ1B, BQ-3		KB/RH, BQ1B, BQ-3	
ITE-Gould (MCCBs)	EF-3, EF-2, HE-3, ET-3, JKL, E-20, KM, JJ, JL	HE-3, EF-3, KM, JJ, JL	EF-2, ET-3, JKL, E-20	
Westinghouse	DS-206, DS-416, DB-25, DB-50, FB-3, HMCP, LB, MCP, BAB-2000, DB-75		DB-25, DB-50, DB-75, FB-3, HMCP, LB, MCP, BAB-2000	DS-206, DS-416
Westinghouse (MCCBs)	HFB, HFD, EHB	HFB	EHB	HFD
General Electric	THFK, THED, TEC, AK-25, AK-2A, AK-2, AKR, TB-63, THJK, TEF-13, TFJ-23		THFK, THED, TEC, AK-25, AK-2A, AK-2, TB-63, THJK, TEF-13, TFJ-23	AKR
ABB	K-1600, K-800, K-3000, K-2000			K-800, K-1600, K-2000, K-3000
McGraw	RHE		RHE	
Square D	QOB-120, KA-3			QOB-120, KA-3
Siemens	RL-800, RLN			RL-800, RLN
Allis Chalmers	LA 600			LA-600

4
HISTORICAL PERFORMANCE DATA FROM INDUSTRY OPERATING EXPERIENCE

This section addresses step number 9 in the LCM planning flowchart in Figure 2-1b. The information compiled in this section is to be used for a comparison or benchmarking to plant-specific conditions and operating experience. The qualitative data is intended as a check list of potential conditions affecting plant-specific performance, while the quantitative failure data may provide insight into the potential for plant-specific enhancements and help identify where improvements can best be made. For instance, if the plant-specific component failure rates are much less (say by a factor of 3) than the generic data indicates, one might conclude that the existing maintenance plan is very effective and further improvements will be difficult to achieve. On the other hand, such a discrepancy between realized and typical failure rates might suggest that maintenance on this equipment could be relaxed if the high reliability seen is the result of excessive maintenance practices. Similarly, if the plant-specific component failure rates are substantially higher than the generic failure rates presented here, or if the contribution of the LVDS to lost power production significantly exceeds the generic (PWR or BWR specific) values, equipment replacement or major changes to maintenance practices may be required. Implied here is the notion that if the reliability performance of an SSC falls below a certain level, replacement or other major maintenance efforts will be required, if only to satisfy Maintenance Rule performance criteria. Finally, because most of the failure data consist of random failures, generic failure rates are indicative of the failure rates that might also be found with new equipment.

It should be noted that this section addresses failures and failure data rather than repair practices and data. In general, repair times will be available from plant records and will depend on plant-specific maintenance practices. The Mean Time To Repair (MTTR) will have an impact on the system availability performance. Caution is in order when using generic failure data for plant-specific application or mixing generic with plant specific data. Mathematically this can be achieved using “Bayesian Updating”, but statistical expertise should be consulted for this.

4.1 Nuclear Industry Experience

4.1.1 Institute of Nuclear Power Operation-INPO, NPRDS and EPIX Data for Breakers

Obtaining applicable and meaningful failures rates for the principal components is a major challenge, particularly failure rates for components that are subjected to different maintenance strategies. Because the breakers represent a large population at the plant and an even larger family industry-wide, the statistics are more reasonable than would be for relatively small SSC populations with significant variation in model and service (i.e. air compressors). For the earlier 480 Volt LCM plan developed as part of the Prairie Island demonstration project [1], the INPO-NPRDS data base and EPIX were interrogated to determine generic and plant-specific failure rates over the past 15 years. The number of breakers represented in the industry fleet in any given year was approximated by the number of breakers per unit times the number of operating plants during the year. It is expected that the actual failure rate will be somewhat higher because not all failures are reported or they are grouped with other SSCs. The raw data of this investigation are given in Table 4-1 and show an average industry-wide breaker failure rate of 0.0169 per year or once in about 60 years. The data are plotted in Figure 4-1 and Figure 4-2 as a function of time to illustrate the change in failure rate versus time.

The data show a significant improvement of the failure rate between 1991 and 1996, amounting to a factor of about 2.7. This drastic reduction appears to be the result of implementing an industry-wide breaker Preventive Maintenance program with a 5 to 71/2 year inspection and overhaul interval. Many plants, however, implemented this breaker PM only for the safety-related breakers and maybe for some of the important to power production breakers. The remaining breakers, including MCCBs, are still mostly treated as run-to-failure.

Table 4-1
Generic Breaker Failure Rate

YEAR	NUMBER OF PLANTS Column A	Number of Failures Column B (From NPRDS)	Number of Breakers Column C (Note 1)	Generic Failure Rate (C/B)
1987	102	805	35700	0.0225
1988	108	862	37800	0.0228
1989	109	816	38150	0.0214
1990	111	814	38850	0.0210
1991	111	857	38850	0.0221
1992	110	847	38500	0.0220
1993	109	718	38150	0.0188
1994	109	542	38150	0.0142
1995	109	456	38150	0.0120
1996	110	326	38500	0.0085
1997	104	309	36400	0.00849
1998	104	300	36400	0.00824
Avrge/Year	108	637	37800	0.0169

Note 1: The number assumes an average of 350 safety-related low voltage breakers per operating unit.

Figure 4-1
Annual Breaker Failure Rate

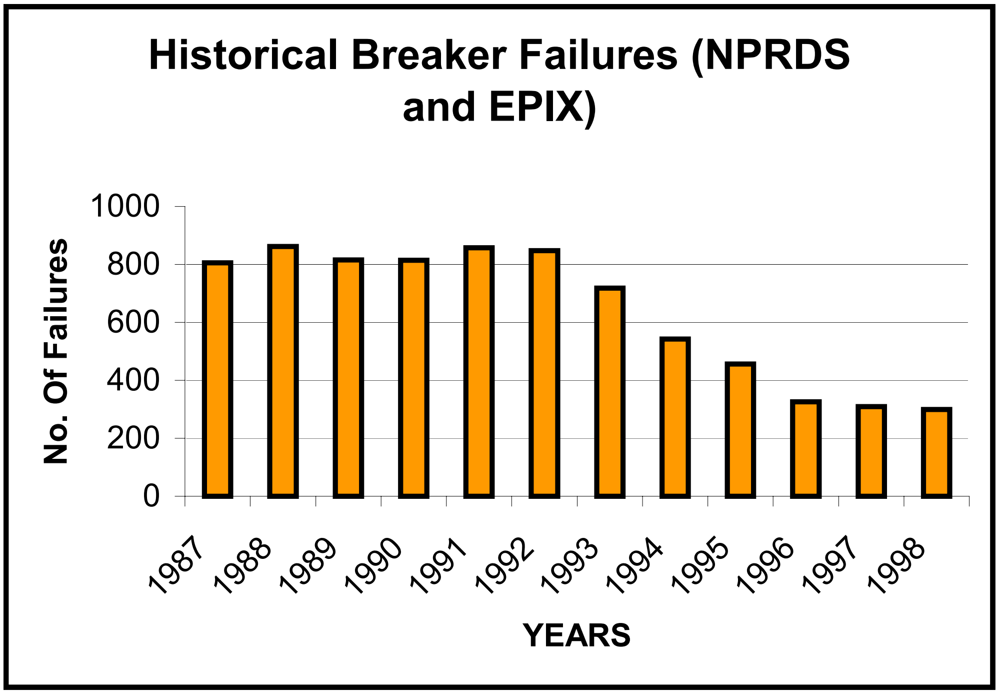
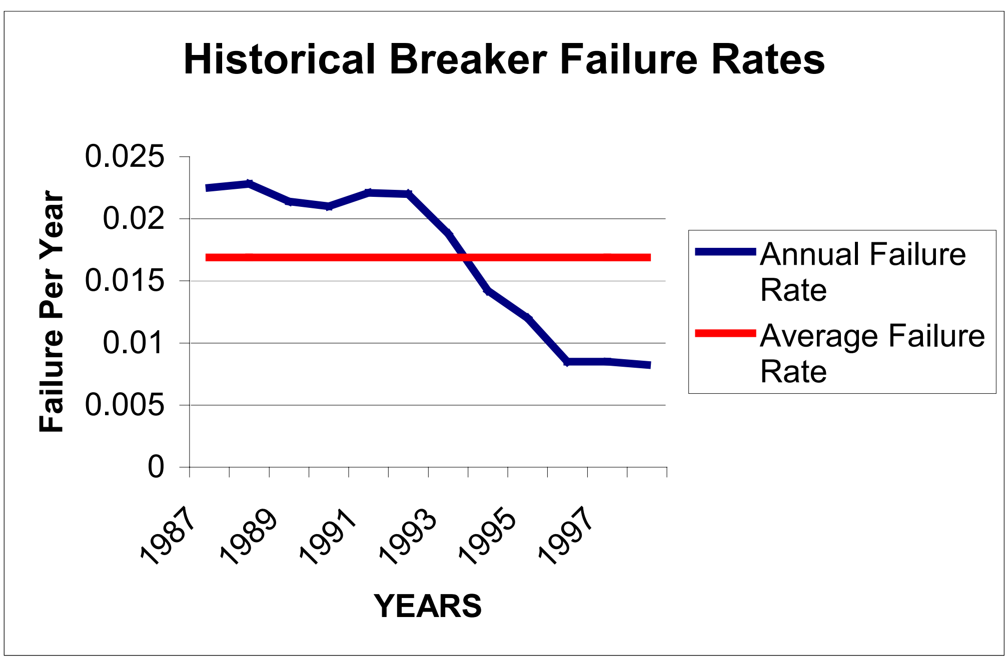


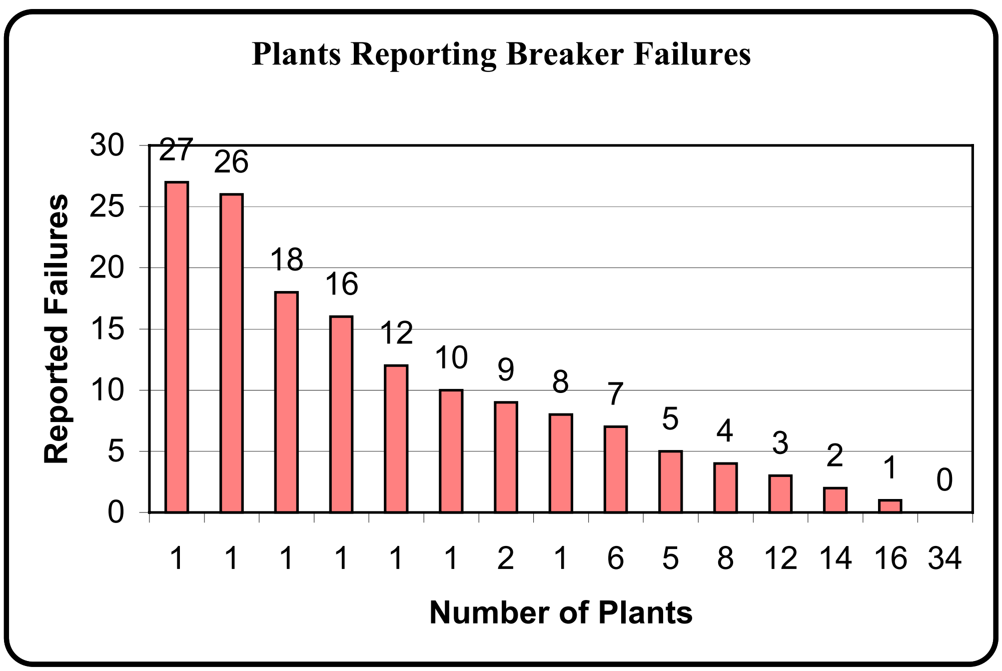
Figure 4-2
Annual Breaker Failure Rate Graph



As part of this study, a separate more recent evaluation of the failure reports cataloged in the EPIX database for the 480 Volt distribution system, was performed. The analysis of this data shows that about 500 failures were reported for the past 6 years (1997 to 2002). Because the data entry in EPIX is far more detailed and explicit than that of NPRDS, it lends itself to better statistical analysis. The following conclusions could be drawn from the data:

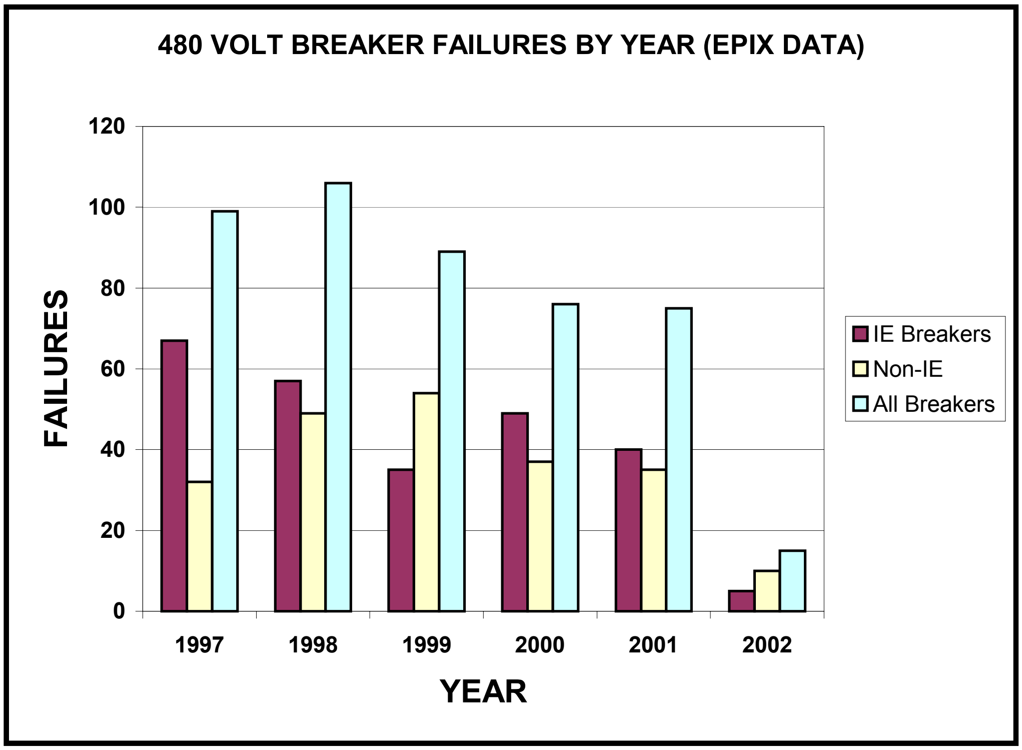
- When sorting the failure reports by operating unit (they are reported on a unit basis), it becomes apparent that reporting is not uniform or consistent. A failure report is filed when a functional failure occurred that caused a loss of the system or train function (or an MPFF occurred). The Maintenance Rule requires reporting of Maintenance Preventable Functional Failures (MPFFs) only and failures due to design, fabrication, installation and assembly usually are not deemed to be MPFFs. The electrical distribution system is typically designed with significant failure resistance; however, a failure of a redundant component is still a loss of function of the redundant train or component. Figure 4-3 shows that 34 plants did not report any breaker failures over the 6-year period, while six plants reported more than 10 failures for the same period. The data clearly shows some inconsistency in reporting failures and the different thresholds utilities may apply to the definition of breaker failure. While not shown on this figure, the failure reports indicate that the plants with the most frequent failure reports are mostly newer plants of the larger size.

Figure 4-3
Reporting of Breaker Failures to EPIX



- In plotting the failures as a function of the year of failure, as shown in Figure 4-4, one can observe that the annual number of breaker failures is fairly constant and may even be declining. Failure reports of safety-related breakers (IE) are a little more frequent than non-safety breakers, but not of statistically significant difference. Because the total population of 480 Volt breakers is not known, exact failure rates cannot be computed from this data, however, an estimate can be made assuming about 700 safety related and important breakers per plant (unit). This would give an annual estimated failure rate of 0.13% (96 failures per year/700 x 104 plants).

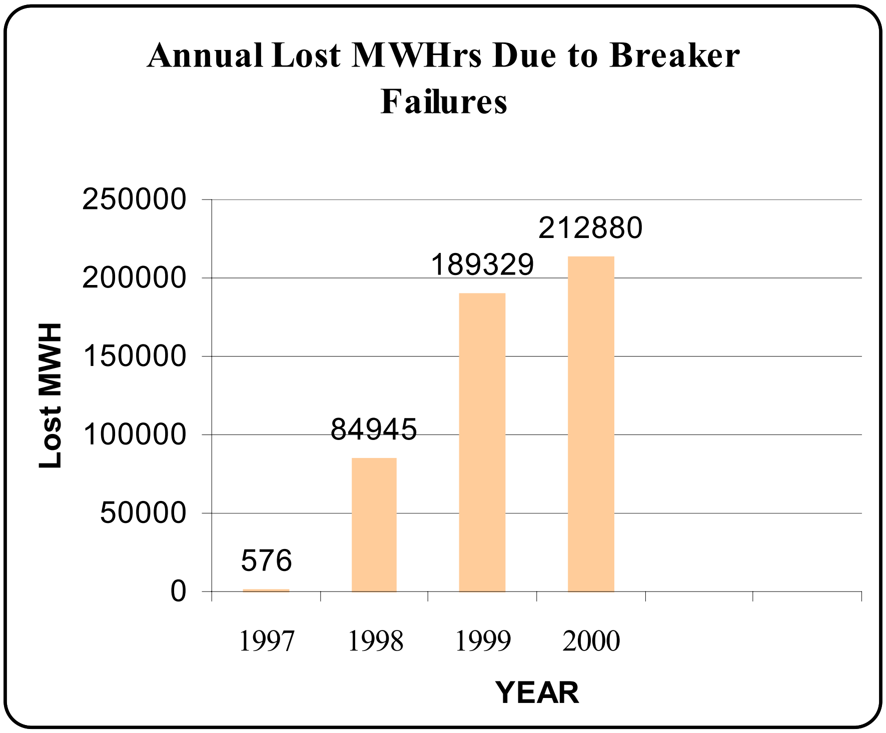
Figure 4-4
Annual Breaker Failures, EPIX



- EPIX data also provide the lost power production associated with breaker failure for the individual events. The trend for the first four years, as shown in Figure 4-5 is definitely increasing (reporting of significant events for 2001 and 2002 is not yet complete). Among the 384 breaker failures in the years 1997 to 2000 (4 years), 12 resulted in a scram or downpower, causing a total of 488,000 lost MWHrs, or an average of almost 41,000 MWH per event. At an average cost of $50.00 per MWH, this amounts to more than 2 million dollars per event. The calculated probability of any of the reported breaker failures causing a lost power event is 12/384 = 0.03125 or about 3%. Calculating the probable financial consequence for any of the 384 breaker failures amounts to almost $63,500 per breaker failure (488,000 MWH x 50 $/MWH/384 failures).

In a separate collaborative EPRI study evaluating EPIX data for 4160 volt switchgear and breakers for the Salem and Hope Creek plants of PSE&G [3] the generic lost power production cost per breaker failure was determined to be $ 193,000. The frequency of a lost power production event was found to be 7.5% per breaker failure with the average cost of lost power production exceeding 3.2 Million dollars per lost power production event.

Figure 4-5
Lost Power Generation from Breaker Failure



- The failure modes, as reported in the EPIX data for the breakers and as shown in Figure 4-6 and expressed in % in Figure 4-7, can be categorized into five principal categories:
  - The breaker is stuck open or fails to close
  - The breaker is stuck closed or fails to open
  - The breaker fails as is or fails to move
  - The breaker performs a spurious operation, includes drifting, out of calibration
  - Failure mode is caused by faulty design, maintenance, installation

  The stuck open/fail to close and the spurious operation failure modes are the predominant ones. Both of these failure modes are the more benign, in that in most cases they do not lead to short circuits or overheating or errant equipment operation.

- Lastly, the breaker failure discovery modes were evaluated and categorized as follows:
  - Discovered by a non-test demand (actual demand or operation)
  - Discovered by a test demand (surveillance testing, exercising, calibrating)
  - Discovered by inspection and/or preventive maintenance (overhaul, refurbishment, replacement)

Figure 4-6
Breaker Failure Modes

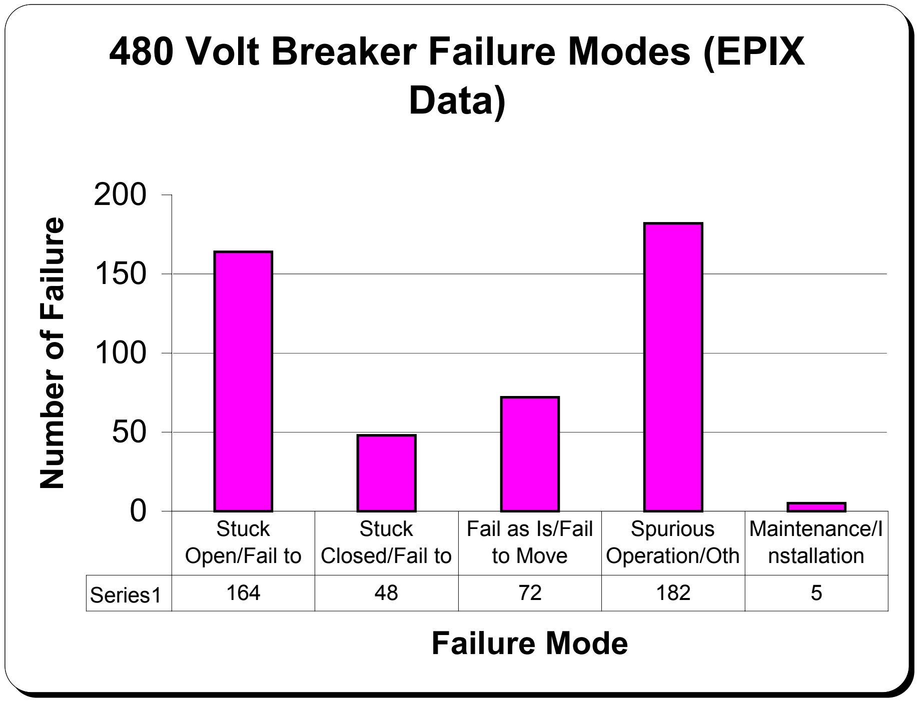


Figure 4-7
Breaker Failure Modes in %

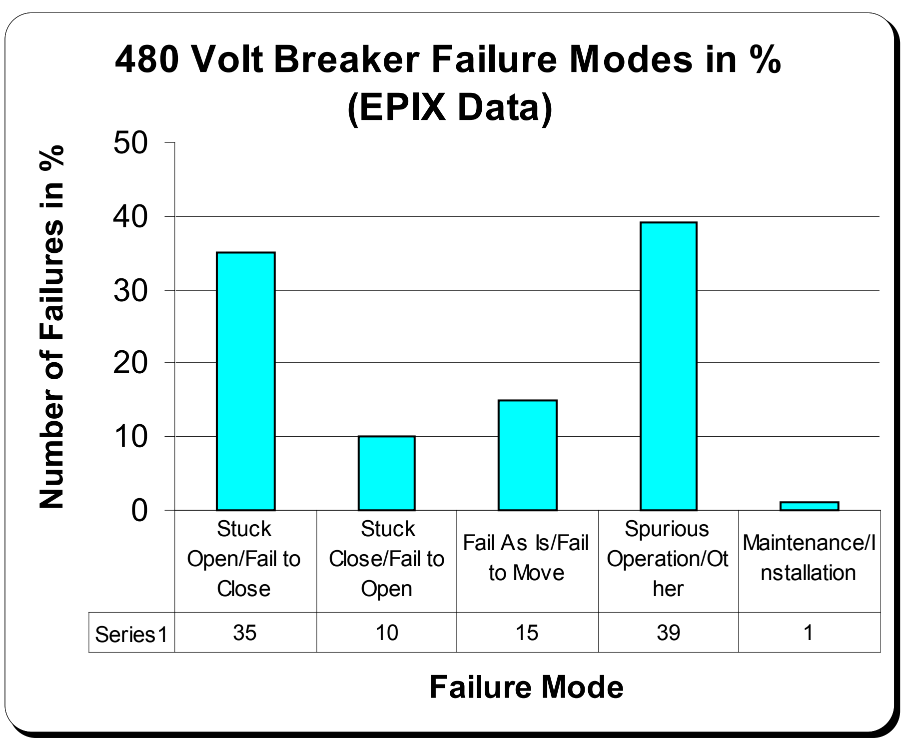
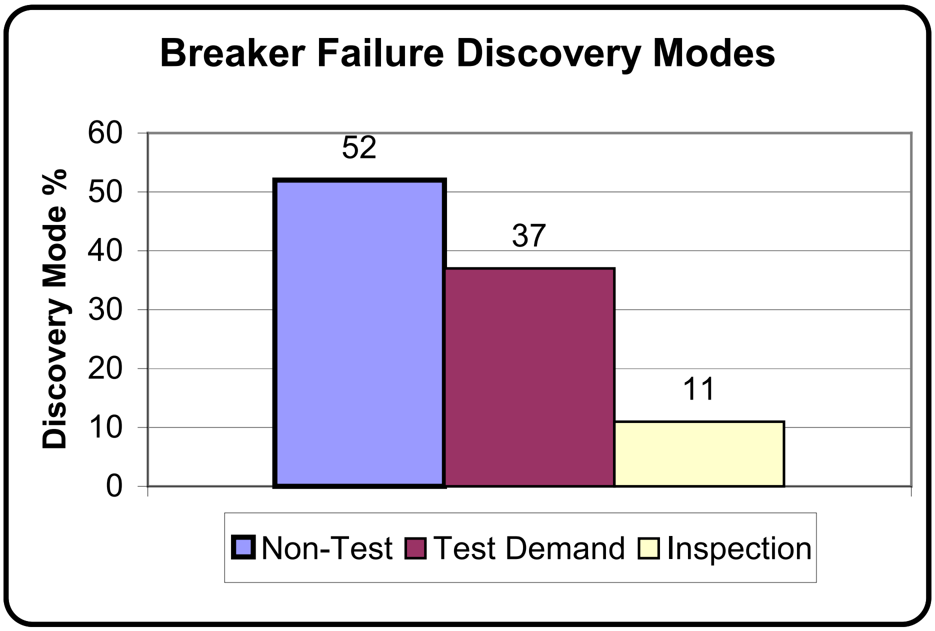


Figure 4-8 provides the breakdown of the discovery modes, concluding that about 50% of breaker failures are detected by preventive maintenance practices and that surveillance testing is more effective than inspection. Though not shown on this graph, the failure report data indicates that very few failures were detected by thermography. This is attributed to the failed state of the breaker (usually no longer energized) that may not be readily detected with thermography. Nevertheless, thermography is a very effective predictive/diagnostic tool for breakers and catches many precursors to failure such as localized heating, degrading/corroded contacts, loose connections and abnormal conditions that lead to ultimate failure.

Figure 4-8
Discovery Modes for Breaker Failures



4.1.2 INPO Data for Molded Case Circuit Breakers (MCCBs)

In 1995, EPRI/NMAC studied circuit breaker performance and maintenance practices to develop a comprehensive industry guidance following NRC generic performance concerns and problems encountered with falsified breaker refurbishment, fake breaker brands and lack of performance certifications. These studies included MCCBs, and EPRI issued a Circuit Breaker Maintenance Guide for MCCBs [5] in October 1995. This Maintenance Guide addresses more than just maintenance; it includes a review of the applicable NPRDS data, assessment of the NRC generic communications and a comprehensive lecture series on the design and operation of MCCBs. The key recommendations and conclusions are discussed here:

- While the NPRDS data analysis provides a detailed breakdown of failure causes and methods of failure detection, as shown here in Figure 4-9 and Figure 4-10, no failure rates are provided and no failure trend versus time is given to assess any aging effects or effectiveness of maintenance programs.

- NMAC evaluated the conclusions of two applicable NRC reports, NUREG-4715 [6] and NUREG-5762 [7] and concluded that the principal recommendations and findings had been adequately incorporated into their study. Of particular note was the finding that infrared monitoring is an effective method to detect MCCB degradation and it was included as an activity in the maintenance guide. NUREG/CR-5762 also recommended vibration testing as part of the mechanical component challenge, however, implementation was not recommended due to lack of test specificity and acceptance criteria.

A unique approach taken in the guide includes the recommendation to categorize the breakers into four service groups, each with its own preventive maintenance tasks and task frequency, commensurate with the relative importance of the breaker. This approach is now very consistent with the most recent equipment reliability guidelines promulgated by INPO in AP-913 [8]. Safety-related breakers are defined as Category 1, while non-safety-related breakers for protection of important plant loads and breakers having experienced a history of failure are placed in Category 2 and are inspected and tested (overload, short circuit and shunt trip) every 5 to 8 years. Other non-safety breakers are inspected and exercised once every 8 to 12 years. The guide cautions that the recommendations are flexible and depend on individual plant conditions and maintenance plans.

Figure 4-9
NPRDS Data Prior to 1995 for MCCBs Subcomponent Failure

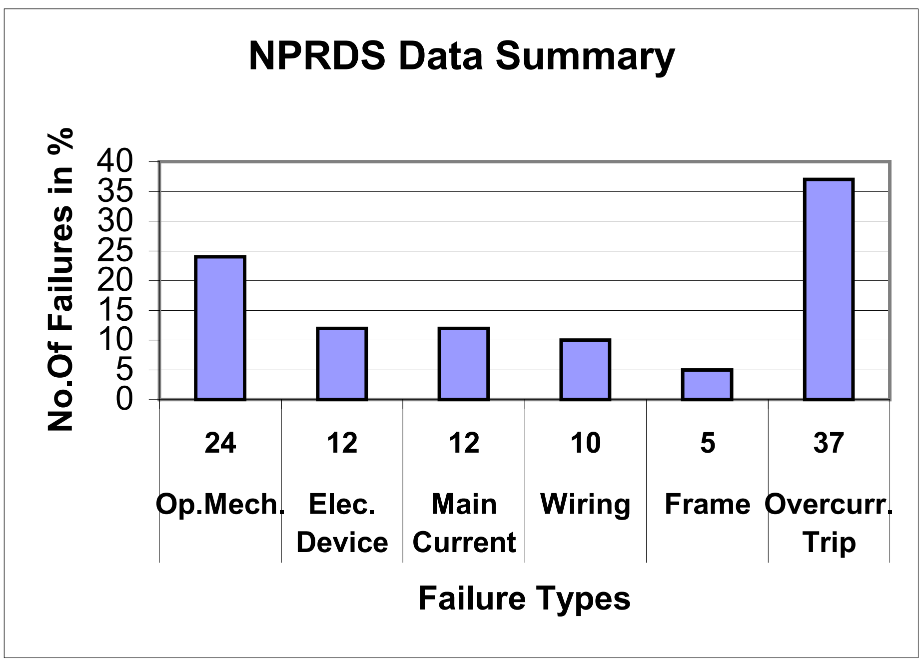
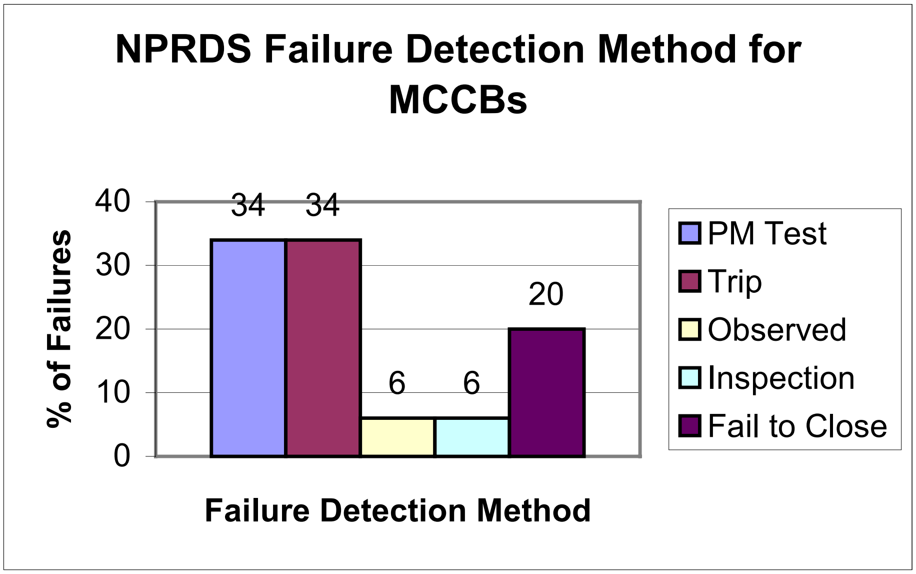
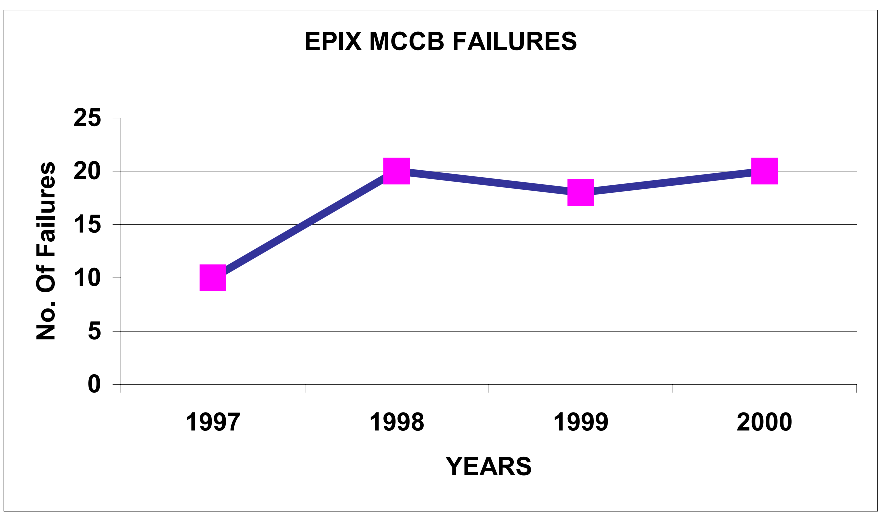


Figure 4-10
NPRDS Data Prior to 1995 MCCB Failure Detection Mode



A search of the EPIX database was conducted by this study for the years 1997 through 2001 to extract the reported failure data for 480 Volt MCCBs. The search returned a total of 68 useful hits, which were analyzed to determine the failure mode and failure cause, discovery method and annual frequency of failure. Figure 4-11 shows the annual failures versus time for the reported time period. This data imply that no distinct trends are present to suggest that age related degradation might be a factor or that maintenance programs have had an impact on the failure rate.

Figure 4-11
MCCB Failures as a Function of Time (EPIX)



4.1.3 Relative Magnitude of LVDS System Failure

In order to provide an industry benchmark for the generic performance and plant impact of electrical distribution systems, this study reviewed the data on industry-wide initiating events for 1987 to 1995, as presented in NUREG/CR-5750, Table D-4 [4]. The relevant data for PWRs and BWRs are tabulated separately in Table 4-2. The event categories associated with the LVDS are "Loss of Vital Bus," "Loss of Non-Safety Bus" and "Loss of AC I&C Bus." The contribution of these events to the total number of events (1,327 events are in the database for PWRs and 658 for BWRs) was calculated and is also shown as a percentage in Table 4-2. The total generic LVDS system contribution was calculated by summing the three applicable event categories to be 3.64% for BWRs and 3.17% for PWRs, a fairly consistent rate for both types of reactors. These factors, after comparison and calibration against the plant-specific data, may be used in the NPV loss calculations to determine the impact on lost power generation attributed to the LVDS system performance and provides a benchmark for plant-specific historic LVDS performance.

It should be stressed that the failure data presented in Table 4-2 are for the entire LVDS and represent both an initiating event for core damage accident scenarios and a plant trip. Though this is of course a consequence of major concern, component (i.e. breakers) and train-specific failure data would probably be more useful in deciding whether and how to enhance the reliability of the LVDS.

Table 4-2
Electrical Distribution Systems Contribution to Plant Faults
(1987-1995 Data, As Amended, [4])

SYSTEM-CATEGORY	Initial Plant Fault		%	
ALL EVENTS	BWR 658	PWR 1327	BWR 100.00	PWR 100.00
LOSS OF OFFSITE POWER	4	13	0.607	0.980
LOSS OF VITAL BUS	*7*	*3*	*1.060*	*0.226*
LOSS OF AIR	13	13	1.976	0.980
FIRE	10	21	1.520	1.583
INADEQUATE CLOSURE OF MSIVs	16	5	2.432	0.377
LOSS OF CONDENSER VAC.	27	13	4.103	0.980
TOTAL LOSS OF FW FLOW	24	62	3.647	4.672
LOSS OF NON-SAFETY BUS	*5*	*20*	*0.760*	*1.507*
LOSS OF AC I&C BUS	*12*	*19*	*1.824*	*1.432*
LOSS OF NON-SAFETY CW	16	34	2.432	2.562

SYSTEM-CATEGORY	Initial Plant Fault		%	
PARTIAL MSIV CLOSURE	11	36	1.672	2.713
PARTIAL LOSS OF FEED WATER FLOW	45	240	6.839	18.086
PARTIAL LOSS OF CONDENSATE. FLOW	13	22	1.976	1.658
EXCESSIVE FEEDWATER	49	61	7.447	4.597
RPS TRIPS	0	40	0	3.014
REACTIVITY IMBALANCE	6	88	0.912	6.631
TURBINE TRIPS	173	284	26.292	21.402
MANUAL REACTOR TRIPS	55	48	8.359	3.617
OTHER TRIPS	154	222	23.404	16.729
SPURIOUS SSAs	14	22	2.128	1.658

4.1.4 Quantitative IOE and Maintenance Information

This sourcebook study solicited and obtained quantitative data through discussions with vendors, suppliers, industry experts and other formal and informal sources, to develop a broad picture of the technology status, anticipated enhancements, new technologies and their applications as well as performance and longevity concerns associated with principal components of the LVDS. While this may not be directly helpful to solve plant-specific LCM concerns, it provides some basic observations of the industry issues for breakers at large and considerations when planning for the future. The following is a summary of expert observations, quotations and viewpoints:

- The breakers in service today are generally of a “Museum Quality”, represented by a technology that is more than 50 to 60 years old. New designs, using solid state arc interruption (passive high powered solid state components that switch off an overload or short circuit) and digital technology, are years or decades away from application in nuclear power plants. In a span of fifty years there are four generations of circuit breakers.
    - The first generation breakers were typically built around the 1940’s. Westinghouse DA, General Electric AL, ITE LX and Allis Chalmer G-Line were some of the typical breakers. These devices included organic insulation such as wood and slate.
    - The second generation included the Westinghouse DB, General Electric AK, ITE K and Allis Chalmers LA line. These breakers make up the majority of the industrial base even today. The internal mechanisms became more complex with more contact assemblies, springs and other moving parts. These breakers were designed with series magnetic trip units, but many of them have been replaced with various solid state trip technologies. The early solid state technology had limited success.

- The third generation included Westinghouse DS, General Electric AKR, ITE Gould K and Allis Chalmer Siemens LA line. All these breakers included solid state trip devices. Many of these breakers are still manufactured today with improvements such as trip logic, insulating material and auxiliary devices.
- The fourth and current generation includes Siemens RL, General Electric WavePro/AKR 7D, ABB K and Cutler Hammer DS II. All these breakers integrate advanced microprocessor-based trip logic providing superior reliability, better resistance to aging, shielding and enhanced functionality. It is important to note that the fourth generation breakers have no asbestos components. All previous generations have discontinued the use of asbestos at various stages.

- The operating experience with breakers has not been very good and they remain one of the key maintenance problems today. The US NRC has issued 184 generic communications (Generic Letters, Bulletins, Information Notices and Circulars) since 1987 to address largely OEM problems from design errors, manufacturing and assembly errors, poor material choices, inadequate lubrication and maintenance guidance and spare parts control (see Section 4.2 and Table 4-10 for detail listing). As many as 40% of breakers being overhauled or refurbished by outside sources (third party contractors) fail their acceptance tests.
- Breakers are complex mechanical assemblies with many moving and stationary parts, tight tolerances, subcomponents and parts that are prone to mechanical damage and distortion and rotating joints that require lubrication and are prone to binding. Corrective maintenance, and overhaul of these breakers requires exceptional skill, knowledge and training of the crafts. As mentioned above, the overall work rejection rate on breakers is about 40%.
- When contracting breaker work to be performed by outside contractors or the OEM, care needs to be exercised when defining the objectives and work scope. There are many terms used in the circuit breaker industry such as overhauls, retrofits, rebuilds, upgrades and remanufactured, each having their own nuance or objective. Remanufacture has generally the most stringent meaning.
- Availability of breakers for safety-related applications is much more restricted than for non-safety-related applications. There is no appropriate standard and design test for life extension methods of low voltage breakers unlike medium voltage applications such as IEEE/ANSI C37 series of Standards [10, 11]. This lack of certification standard has caused the industry to develop its own individual set of vendor-specific guidelines [51, 52].
- An operating plant will spend between one and three million Dollars per year in breaker maintenance costs, not including scheduled replacements or upgrades.
- Low voltage breakers, including MCCBs, are not expected to reach the 40-year plant life, much less be sufficiently reliable for the license renewal period. Refurbishment or overhaul will become more difficult and expensive as the spare parts and overhaul kits disappear form the market.
- The new breakers and MCCBs on the market today are more reliable than their forefathers due to fewer moving parts, better materials and lighter construction (reduces vibration and impact loads during operation).
- MCCBs cannot be overhauled or refurbished because of their sealed housing. The original grease does not have an adequate life and causes breakers to “stick” in the open, closed or as-

is position. Replacement with a new one is the required action. Stockpiling MCCBs for long periods of time may not be appropriate. The grease degradation problem will continue in the warehouse and force ultimate replacement with a new technology or alternative breaker design. Interface engineering and qualification (seismic, environmental) is very costly and typically leads to a complete replacement of the enclosure (bucket) or cell and all its contents.

- Many breaker types and models have become obsolete or will be obsolete within the next five to ten years, as shown on Table 3-1. With a little bit of luck and a lot of time, parts may be found for most circuit breakers including old vintages. A search of web sites and trade magazine advertisers identified over one hundred different suppliers and third party vendors of hard-to-find parts and parts re-builders that provide parts such as spring mechanism and contacts, trip units, arc chutes, etc. The primary problem is a lack of uniform quality control and certification on these parts.

- Choosing the correct lubricant plays a key role in the proper performance, maintenance and overhaul of electrical circuit breakers. The proper choice of lubricant can be made by following the OEM's specifications or by examining the conditions of the application. Over 50 different lubricants have been used, many of which are no longer produced or cannot be found. This problem is prominent amongst all the electric utilities, which are trying to maintain aging equipment with obsolete lubricant recommendations. Great difficulties are found in purchasing many recommended products. As many substitutes are tried, an overstock of redundant lubricants results. This compounds the problem since some lubricants have a limited shelf life, control of what actually goes into the equipment is potentially lost, and misapplications can result.

  Lack of lubrication, using the wrong lubrication product, and inappropriate lubrication maintenance procedure including time intervals has led to a significant number of costly failures in the electrical industry. When switching lubricants, the possibility of mixing different non-compatible materials exists and requires careful degreasing of the entire apparatus.

  Some chemical and oil companies have developed lubrication guides featuring lubricant recommendations for virtually all-low voltage circuit breakers manufactured in the past 50 years. This resource provides for lubricant consolidation, informed decision and extended life with some new synthetic greases. Mobilgrease 28 has become an industry favorite long life grease for breaker applications.

4.1.5 Other Sources of Generic Failure Data

The plant's Probabilistic Safety Analysis (PSA) typically does not model breakers individually, but if they are modeled, a typical failure rate for breakers is expressed in failure per demand and is in the range of 4.4xE-4. For most safety systems, the only challenge to the breakers is the system surveillance test conducted monthly (i.e. EDGs) or quarterly. This would convert to an annual failure rate of 5.3xE-3 (or 0.53% per year, if challenged monthly) and 1.8xE-3 (or 0.18% per year, if challenged quarterly). Both of these rates are substantially lower than those based on the NPRDS data (Table 4-1 shows a current average of 0.85%), but higher than those estimated from the more recent EPIX data (Figure 4-4).

The European power plants, specifically those of the French utility EDF [9], have been developing failure rates from the actual plant performance data. For breakers in the 115 to 500Volt service, a failure rate of 0.35E-6 per hour has been established; this is equivalent to 3.1xE-3 failures per year (or 0.31%), fairly consistent with the PSA data discussed above.

The IEEE Standards Organization discusses low voltage breaker reliability and failure data in Standard IEEE 493-1997 [12]. Table 4-3 is a reproduction of the pertinent data from IEEE 493 and represents general industrial breaker data. Utility data appear not well represented and the data surveys did not include safety-related equipment. However, the failure rates are reasonably consistent with those experienced in the power industry as shown in the NPRDS and EDF data. Of significance is the substantially higher failure rate of the medium voltage (above 600V) breakers.

Table 4-3
Summary of Failure Rates for all Electrical Equipment
IEEE 493-1997 (1976-1989)

Equipment	Equipment Subclass	Failure Rate
Circuit Breakers	Fixed (including molded case)	0.0052
	0–600 V—All sizes	0.0042
	0–600 A	0.0035
	Above 600 A	0.0096
	Above 600 V	0.0176
	Metalclad drawout type—All	0.0030
	0–600 V—All sizes	0.0027
	0–600 A	0.0023
	Above 600 A	0.0030
	Above 600 V	0.0036
Transformers	All liquid filled	0.0062
Motor Starters	Contact Type 0-15000V	0.0146

4.1.6 Maintenance Rule Requirements

The EPRI “SYSMON” software program [13] contains 37 system monitoring plans with recommendations for performance monitoring. Three electrical distribution systems are applicable to the LVDS:

- 120 Volt AC Vital Instrument Power

- Class IE 480 VAC Power
- Class IE 125 VDC Power

Summaries of the system monitoring plans are reproduced from the EPRI Database [13] in Figure 4-12, Figure 4-13, and Figure 4-14 and show the performance parameters to be monitored consisting of essentially plant level criteria (MPFFs, Scrams, ESFAs and LCO time). These criteria would apply for plants that do systems performance monitoring at the electrical distribution system level. Some plants are defining the electrical distribution system scope more narrowly, such that the breakers and/or motor control centers are assigned to the individual mechanical systems. In this case, a breaker failure would be considered a loss of the primary system function rather than the electrical distribution system. The Maintenance Rule requires identification, trending and reporting (to EPIX) of Maintenance Preventable Functional Failures (MPFFs) and more importantly repetitive MPFFs. Repetitive MPFFS are defined as failures occurring in similar or same components with the same cause. For breakers, this would typically require cross-system monitoring of similar breaker types and models. From the generic communications it can be deduced that many of the identified breaker issues are of the same cause, particularly the lubrication issues. In order to provide timely indication of changing breaker performance, trending of breaker failure rates, detection of precursors as well as emerging degradation and aging issues, a plant wide breaker failure monitoring program should be part of LCM planning.

For some plants, the LVDS are considered risk significant under the definitions used in the Maintenance Rule. Under those circumstances, the LVDS may feature system specific performance criteria that include reliability and/or availability. These parameters are monitored against specified acceptance criteria. Due to the system’s low tolerance to loss of function, the availability parameters are typically in the range of 99.5% or higher for a normally operating system.

Figure 4-12
SysMon Recommendations for 120VAC Vital Instrument Power

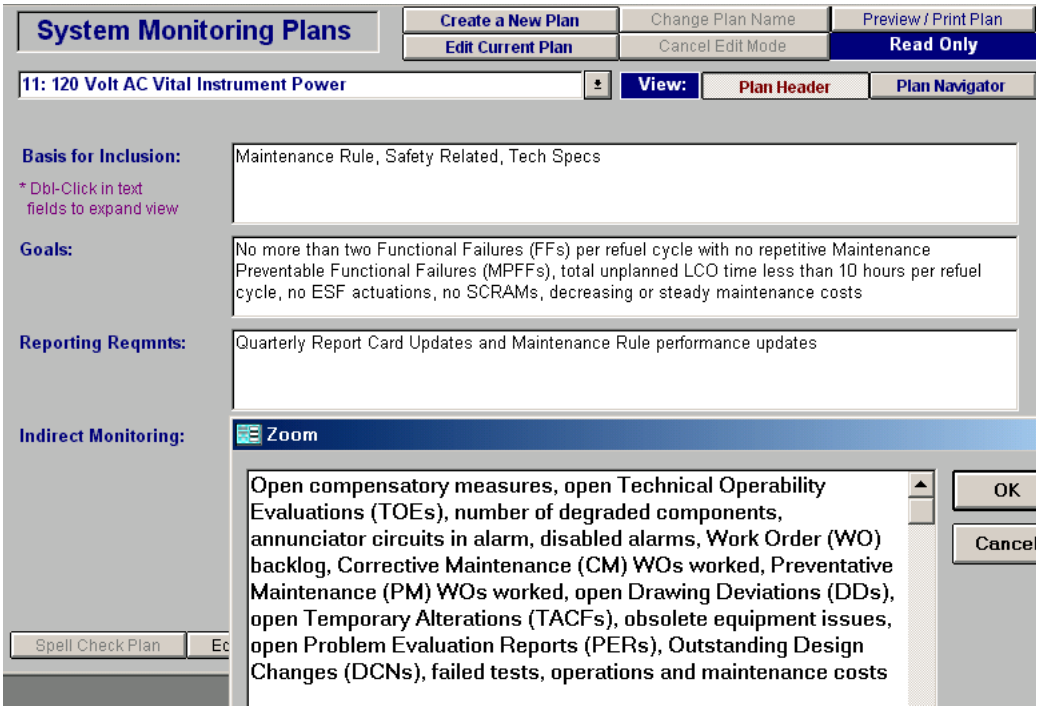


Figure 4-13
SysMon Recommendations for Class IE 480VAC Power

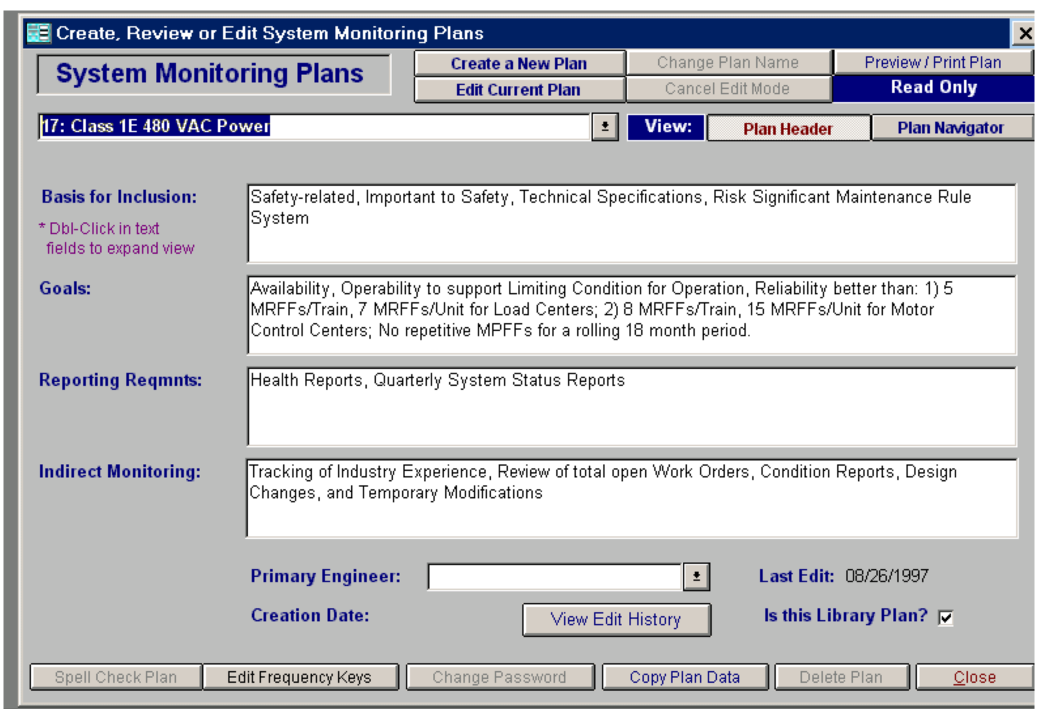
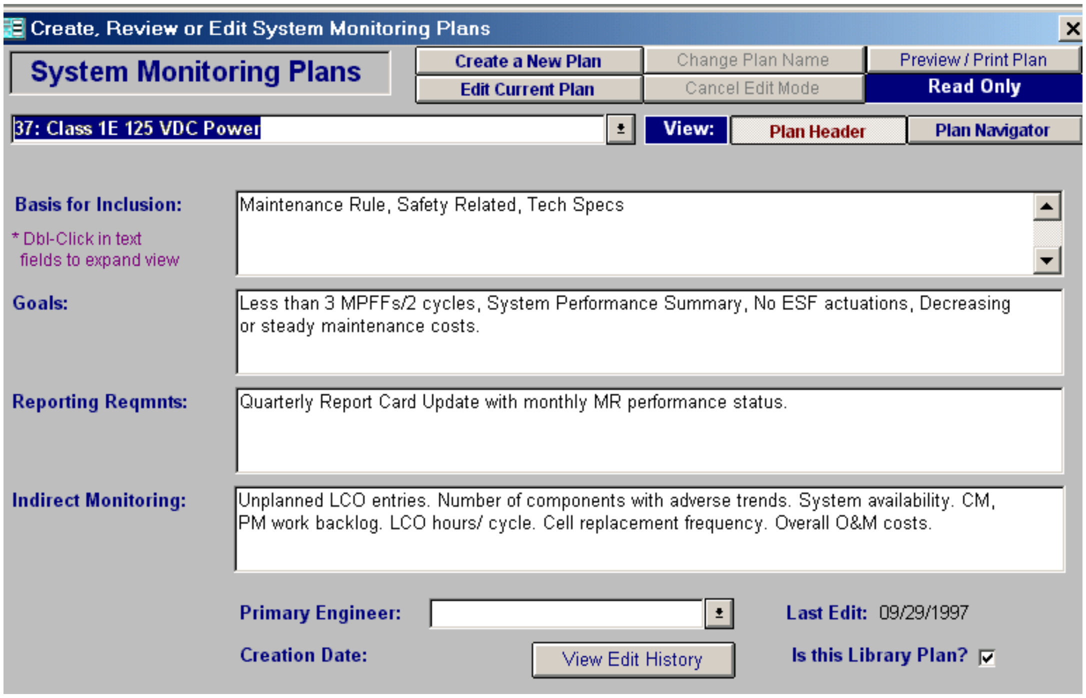


Figure 4-14
SysMon Recommendations for Class IE 125VDC Power



4.1.7 EPRI PM Basis Templates

The EPRI Preventive Maintenance Basis Database [14] provides generic recommendations for preventive and diagnostic/predictive maintenance activities to be applied to the most important and representative components in nuclear power plants. Because the recommendations have been established by an industry consensus, consisting of participating utilities, vendors/OEMs and other components experts, they should be considered an optimum set of PM activities when assessing plant-specific maintenance activities for LCM planning of electrical components for which a template is available. The recommendations take into account the plant-specific conditions of environment, service duty and functional importance, consistent with the component selection and categorization process given in the INPO Reliability Process Description, AP-913 [8], (i.e. critical, non-critical and run-to-failure).

While the referenced and published version of the PM Basis cited here is version 3.01 [14], EPRI has completed a revision to this version, to be issued sometime in 2002 as version 4.0.

Table 4-4
EPRI PM Basis for Low Voltage Switchgear

Task Name	CHS	CLS	CHM	CLM	NHS	NLS	NHM	NLM
Thermography - Breaker and Cubicle (including bus)	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Breaker - Visual Inspection	2Y	2Y	AR	AR	AR	AR	NR	NR
Breaker - Detailed Inspection	4Y	4Y	6Y	6Y	6Y	6Y	6Y	6Y
Breaker - Overhaul	8Y	8Y	10Y	10Y	10Y	10Y	10Y	10Y
Cubicle - Detailed Inspection	6Y	6Y	6Y	6Y	6Y	6Y	6Y	6Y
Functional Test	2Y	2Y	2Y	2Y	2Y	2Y	2Y	2Y

Table 4-5
EPRI PM Basis for Protective Relays

Task Name	CHS	CLS	CHM	CLM	NHS	NLS	NHM	NLM
As-Found Testing and Calibration	NA	2Y	NA	4Y	NA	4Y	NA	8Y
Scheduled Replacement	NA	8Y	NA	8Y	NA	8Y	NA	8Y
No Task	NR	NR	NR	NR	NR	NR	NR	NR

Table 4-6
EPRI PM Basis for Motor Control Centers

Task Name	CHS	CLS	CHM	CLM	NHS	NLS	NHM	NLM
Thermographic Scan (Buckets and MCC Housing)	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Clean, Inspect, Tighten, and Cycle (Buckets and MCC Housing)	5Y	5Y	5Y	5Y	10Y	10Y	10Y	10Y
Circuit Breaker Tests	10Y	10Y	10Y	10Y	NR	NR	NR	NR

The abbreviations in the columns of the above Tables are standard EPRI and INPO-AP-913 nomenclature as follows:

C	critical	N	non-critical
H	high duty cycle	L	low duty cycle
S	severe service	M	mild service
Y	Years	AR	As required
NR	Not Required	NA	Not Applicable

As presented in Section 4.4, these Templates are used as a guidance to evaluate plant-specific preventive maintenance programs and activities with respect to best industry practices.

4.1.8 EPRI and NMAC Breaker Maintenance Guides

Over the last ten years, EPRI-NMAC maintained and managed a Breaker Users Group with participation from utilities, OEM representatives and other equipment vendors and experts. The Group developed or co-sponsored a series of Breaker Maintenance and Overhaul Guides for low voltage breakers and Molded Case Circuit Breakers [5 and 15 to 24]. Additionally, the Group issued a number of Maintenance and Overhaul Guides for medium voltage breakers (which are not part in the scope of this sourcebook) and undertook evaluation of a number of industry breaker issues [27, 28, 29].

The latest versions of the Maintenance and Overhaul Guides present improvements over the older versions and address many of the Generic Communications (NRC and INPO). The older versions, however, are still a valuable reference in that they contain some failure data, failure modes and vendor recommendations for certain breaker types. The preventive maintenance and overhaul recommendations of the applicable guides have been summarized in Table 4-7. The data show that the preventive maintenance attributes are fairly consistent across the various breaker types and models, with the exception of the MCCBs. It is noted that the Guides recommend that the vendor or model specific Breaker Maintenance Guide recommendations be used in lieu of the more generic recommendations given in the EPRI PM Basis Templates.

Table 4-7
EPRI-NMAC Breaker Maintenance Guides – Summary

Breaker Type → PM Attributes ↓	ABB K-Line [15,16,17]	GE AK-AKR [18,19,20]	WEST DS, DB [22,23,24]	All MCCBs [5]
Routine PM Frequency	4-6 Years	5 Years (1 Y-GE)	<6 Years <500 cycles	5-8 Y Cat 2 6-12Y Cat 3
As Found Insp. and Tests	X	X	X	Not Perf.
Detailed Inspection	X	X	X	X
Arc Chutes	X	X	X	NA
All Wiring and Contacts	X	X	X	X
Operating Mechanism	X	X	X	X
Lubrication	X	X	X	NA
Cubicle Inspection	X	X	X	X
Mechanical Adjustments	X	X	X	NA
Cleaning	X	X	X	Not Perf.
Testing	X	X	X	X
Overhaul Frequency	<13 Years	6-10 Years [22]	8-12 Years [23]	No Overhaul is Performed
As-Found Inspections, Tests	X	X	X	NA
Complete Disassembly	X	X	X	NA
Inspection	X	X	X	NA
Parts Replacement (Kits)	X	X	X	NA
Cleaning and Lubrication	X	X	X	NA
Reassembly and Installation	X	X	X	NA
Measurements and Adjustments	X	X	X	NA
Post Overhaul Testing	X	X	X	NA

In reviewing the Breaker Maintenance Guides, two weaknesses were noted:

- Explicit inspection for wear and checking of wear parts was not included in the Routine PM recommendations (corrosion, loose parts, missing items, dirt, overheating, physical damage, tightness are attributes that ARE checked), even though wear and corrosion (due to lack of or poor lubricants) are the predominant degradation and failure mechanisms of the moving mechanical parts of the breakers (Operating Mechanism). These parts get checked or replaced only during the Overhaul PM every 10-12 years, which does not appear adequate for breakers of high cycle duty.
- The guidance and recommendation for lubrication tasks do not adequately reflect the vendor concerns [23] when lubrication products are changed (i.e. switching to Mobil 28). It is important to remove all existing grease, including that inside bearings and bushings, before applying the new products, unless the new grease has been demonstrated to be compatible with the old ones. Many products are not compatible (organic, inorganic and synthetic), such that a mix could render the breaker inoperable.

In addition to the general guidance for PM and Overhaul frequency, the older guides provide a tabular range of time based task frequencies [16,20,22] which are useful to benchmark plant-specific task frequencies until such time that PM experience may justify significant deviation. A typical breaker maintenance schedule is reproduced from the breaker maintenance guides in Table 4-8 below.

Table 4-8
Typical EPRI-NMAC Breaker Guide Maintenance Scheduling

Category	Maintenance Action	Periodicity
Safety-related	1. Routine Inspection, Test, Adjustments	Each Refueling Outage (18/24 Months)
	2. Complete Overhaul	8-12 Years
	3. Lubrication (General Application Breakers)	4-6 Years
	4. Test OCTD Current Sensors	4-6 Years
	5. Routine Inspection, Test, Adjustment and Lubrication (Reactor Trip Breakers)	200 cycles or 18 Months
Non-safety-related	1. Routine Inspection, Test, Adjustments	Every Second Refueling Outage (36/48 Months)
	2. Complete Overhaul	8-12 Years
	3. Lubrication	4-6 Years
	4. Test OCTD Current Sensors	4-6 Years
After Over-current Condition	1. Inspection, Test and Adjustment	As Soon as possible

4.1.9 Other Applicable EPRI-NMAC Reports

A number of “Good Engineering Practices” and long-term maintenance recommendations for breakers have been published by EPRI-NMAC with the participation of the Breakers Owners Group. These are summarized as follows:

- There have been many Generic Communications and OEM service advisory letters regarding the unsatisfactory performance of lubricants used in the original breakers and during maintenance activities. Some of the lubricants have a tendency to harden as they age or are aging prematurely; others are attracting dirt and carry the contamination into the wear parts. Mobilgrease 28 has been in use for the last 15 years and was initially applied to GE circuit breakers. Because of its superior performance with respect to its life expectancy, industry wanted to apply this lubricant to all breakers. EPRI-NMAC sponsored the research to evaluate and qualify Mobilgrease 28 by testing it using two ABB K-1600 circuit breakers [25]. The results confirmed that the Mobilgrease 28 lubricant is equivalent or exceeds the performance of the currently applied grease. The OEM concerns include the need to completely degrease the breaker before applying the new grease and, because Mobil 28 is more “slippery”, it may lead to higher operating velocities and associated impact and vibration. It is noted that individual utilities have qualified Mobil 28 for application on a number of different breakers.

- The regulatory authorities have been pressing the industry to perform "Reduced Control Voltage Testing" of low and medium voltage circuit breakers to demonstrate operability margins at reduced bus voltage. A utility working group, under the management of EPRI-NMAC, undertook the task to evaluate the merits and pitfalls of reduced voltage testing [26]. The conclusions are that there is an industry consensus that reduced control voltage testing is a good engineering practice, but that trending is not recommended. The test is a go/no-go test (pass or fail).

EPRI-NMAC in collaboration with the Circuit Breaker Users Group, reviewed and evaluated utility procedures and vendor manuals and solicited input from experts, manufacturers and other organizations to develop guidance for circuit breaker timing and travel analysis for low and medium voltage breakers [27]. The general industry consensus documented in the report is that breaker timing and travel analysis and testing provides some indication of specific circuit breaker subcomponent conditions, but does not provide a comprehensive assessment of the overall breaker condition. Trending of timing data is not recommended; these tests are usually considered pass or fail tests. It is to be noted that primary injection testing of low voltage circuit breakers includes a tripping time test.

4.1.10 Current PM Activities and Candidate PM Tasks

Using the recommendations provided in Table 4-4 through Table 4-6 (EPRI PM Basis) and Table 4-7 and Table 4-8 (NMAC Guides), as well as actual plant procedures and PM programs, a consolidated list of current PM activities and candidate PM tasks is presented in Table 4-9. As noted, there is little consistency in the time directed frequencies of the tasks, largely due to the differing plant programs. Some plants perform sample testing or exercising of breakers, have implemented diagnostics and failure trending or have installed more modern breaker models, such that longer or shorter PM intervals are applied and appropriate. Plant-specific service conditions, environment and manufacturers recommendations may be additional reasons for deviating from the norm.

Table 4-9
Preventive Maintenance Activities for LVDS Equipment

Equipment Item	Maintenance Activity	Frequency and Source Reference
Breakers	Routine Breaker PM	4-6 Y [15-24], 5Y [1], 1Y [18-GE], <500 cycles or 6 Y[22,23,24]
	Breaker Detailed Inspection	4-6 Y [14]
	Routine PM, K-Line Breakers	3Y [1]
	Routine Breaker Lubrication	4-6 Y [16,20,22]
	Test OCTD Current Sensors	4-6 Y [16,20,22]

Equipment Item	Maintenance Activity	Frequency and Source Reference
	Complete Overhaul	8-12 Y [23], 6-10 Y [22], <13 Y [17], 8-10 Y [14]
	Critical Breaker Visual Inspection	2 Y [14]
	Breaker and Cubicle Thermography	1 Y [14]
	Breaker Functional Test	2 Y [14]
	Routine PM for Non-Safety Bus Breaker	3 Y [1]
	RPS Breaker PM	Each Refuel [1]
	RPS Surveillance Test	Monthly [1]
MCCBs	Critical MCCB PM	5-8 Y [5]
	Non-critical MCCB PM	6-12 Y [5]
	MCCB Bucket Clean, Inspect, Test	6 Y [1]
Buses	Safety and NSF Bus PM	6 Y [1]
	Bus Trip/Relay Testing	5 Y [1]
Relays	Testing and Calibration	2-4 Y [14]
	Thermography	1 Y [14]
Motor Control Centers (MCCs)	Clean, Inspect, Tighten, and Cycle (Buckets and MCC Housing)	5-10 Y [14]

4.2 Generic Communications

4.2.1 NRC Generic Communications

Most of the generic communications issued by the USNRC in the form of Information Notices, Bulletins and Generic Letters have been identified and addressed in the respective EPRI-NMAC Breaker Maintenance Guides discussed above. Similarly, the underlying Service Advisory Letters (SALs) issued by the OEMs have been listed and incorporated as necessary into the Guides.

A search for breakers of the EPRI Generic Communications Database [28] identifies 13 NRC Bulletins related to low voltage circuit breakers, 62 Information Notices (1980 to 1999) and one Generic Safety Issue (GSI-055). The list of the relevant GC documents and their titles are given in Table 4-10. After implementation of an industry-wide effort on circuit breaker preventive maintenance program in the mid 1990s, there was a significant reduction in the breaker failure rate as well as the number of generic communications issued by the NRC. In fact, only four Information Notices were issued since 1997. It is not clear, if this is a meaningful trend, but it provides an indication that the trend is in the positive direction.

Table 4-10
Potentially Relevant Generic Communications For Breakers
(Data Through April 2001)

Document Number		Document Title
Bulletin	71002	No Title - Involves PWR Reactor Trip Circuit Breakers
Bulletin	73001	Faulty Overcurrent Trip Delay Device in Circuit Breaker
Bulletin	74008	Deficiency in the ITE Molded Case Circuit Breakers, Type HE-3
Bulletin	78005	Malfunctioning of Circuit Breaker Auxiliary Contact Mechanism - General Electric Model CR105X
Bulletin	79009	Failures of GE Type AK-2 Circuit Breaker in Safety-related Systems
Bulletin	79011	Faulty Overcurrent Trip Devices in Circuit Breakers for Engineered Safety Systems
Bulletin	83001	Failure of Trip Breakers (Westinghouse DB-50) to Open on Automatic Trip Signal
Bulletin	83004	Failure of the Undervoltage Trip Function of Reactor Trip Breakers
Bulletin	83008	Elect. Circuit Breakers with Undervoltage Trip...in Safety-Related Applications other than the Reactor Trip System
Bulletin	85002	Undervoltage Trip Attachments of Westinghouse DB-50 Type Reactor Trip Breakers
Bulletin	88001	Defects in Westinghouse Circuit Breakers
Bulletin	88010	Nonconforming Molded-Case Circuit Breakers
Bulletin	8810S1	Nonconforming Molded-Case Circuit Breakers
IN	80031	Maloperation of Gould-Brown Boveri 480 Volt Type K-600S and K-600S Circuit Breakers
IN	81006	Failure of ITE Model K-600 Circuit Breaker
IN	83018	Failures of The Undervoltage Trip Function of Reactor Trip System Breakers
IN	83050	Failures of Class 1E Safety-Related Switchgear Circuit Breakers to Close on Demand
IN	83076	Reactor Trip Breaker Malfunctions (Undervoltage Trip Devices on GE Type AK-2-25 Breakers)
IN	83084	Cracked and Broken Piston Rods in Brown Boveri Electric Type 5HK Breakers

IN	85016	Time/Current Trip Curve Discrepancy of ITE/Siemens-Allis Molded Case Circuit Breaker
IN	85051	Inadvertent Loss or Improper Actuation of Safety-Related Equipment
IN	85058	Failure of a General Electric Type AK-2-25 Reactor Trip Breaker
IN	85064	BBC Brown Boveri Low-Voltage K-Line Circuit Breakers, With Deficient Overcurrent Trip Devices Models OD-4 and OD-5
IN	85093	Westinghouse Type DS Circuit Breakers, Potential Failure of Electric Closing...because of Broken Spring Release Latch Lever
IN	8558S1	Failure of a General Electric Type AK-2-25 Reactor Trip Breaker
IN	86062	Potential Problems in Westinghouse Molded Case Circuit Breakers Equipped with a Shunt Trip
IN	87012	Potential Problems with Metal Clad Circuit Breakers, General Electric Type AKF-2-25
IN	87035	Reactor Trip Breaker, Westinghouse Model DS-416, Failed to Open on Manual Initiation from the Control Room
IN	87041	Failures of Certain Brown Boveri Electric Circuit Breakers
IN	87061	Failure of Westinghouse W-2-Type Circuit Breaker Cell Switches
IN	8735S1	Reactor Trip Breaker, Westinghouse Model DS-416, Failed to Open on Manual Initiation from the Control Room
IN	8761S1	Failure of Westinghouse W-2-Type Circuit Breaker Cell Switches
IN	88038	Failure of Undervoltage Trip Attachment on General Electric Circuit Breakers
IN	88042	Circuit Breaker Failures Due to Loose Charging Spring Motor Mounting Bolts
IN	88044	Mechanical Binding of Spring Release Device in Westinghouse Type DS-416 Circuit Breakers
IN	88045	Problems in Protective Relay and Circuit Breaker Coordination
IN	88046	Licensee Report of Defective Refurbished Circuit Breakers
IN	88054	Failure of Circuit Breaker Following Installation of Amptector Direct Trip Attachment
IN	88075	Disabling of Diesel Generator Output Circuit Breakers by Anti-Pump Circuitry
IN	89021	Changes in Performance Characteristics of Molded-Case Circuit Breakers
IN	89029	Potential Failure of ASEA Brown Boveri Circuit Breakers During Seismic Event
IN	89045	Metalclad, Low-Voltage Power Circuit Breakers Refurbished With Substandard Parts
IN	89086	Type HK Circuit Breakers Missing Close Latch Anti-Shock Springs

IN	8945S1	Metalclad, Low-Voltage Power Circuit Breakers Refurbished With Substandard Parts
IN	8945S2	Metalclad, Low-Voltage Power Circuit Breakers Refurbished With Substandard Parts
IN	90041	Potential Failure of General Electric Magne-Blast Circuit Breakers and AKCircuit Breakers
IN	90043	Mechanical Interference With Thermal Trip Function in GE Molded-Case Circuit Breakers
IN	9043S1	Mechanical Interference With Thermal Trip Function in GE Molded-Case Circuit Breakers
IN	91015	Incorrect Configuration of Breaker Operating Springs in General Electric AK-Series Metal-Clad Circuit Breakers
IN	91078	Status Indication of Control Power for Circuit Breakers Used in Safety-Related Applications
IN	92003	Remote Trip Function Failures in General Electric F-Frame Molded-Case Circuit Breakers
IN	92029	Potential Breaker Mis-coordination Caused by Instantaneous Trip Circuitry
IN	92044	Problems With Westinghouse DS-206 and DSL-206 Type Circuit Breakers
IN	92051	Misapplication and Inadequate Testing of Molded-Case Circuit Breakers
IN	9251S1	Misapplication and Inadequate Testing of Molded-Case Circuit Breakers
IN	93009	Failure of Undervoltage Trip Attachment on Westinghouse Model DB-50 Reactor Trip Breaker
IN	93022	Tripping of Klockner-Moeller Molded-Case Circuit Breakers Due to Support Lever Failure
IN	93026	Grease Solidification Causes Molded Case Circuit Breaker Failure to Close
IN	93064	Periodic Testing and Preventative Maintenance of Molded Case Circuit Breakers
IN	93065	Reactor Trips Caused By Breaker Testing With Fault Protection Bypassed
IN	93075	Spurious Tripping of Low-Voltage Power Circuit Breakers With GE RMS-9 Digital Trip Units
IN	9326S1	Grease Solidification Causes Molded-Case Circuit Breaker Failure to Close
IN	9385R1	Problems With X-Relays in DB- and DHP-Type Circuit Breakers Manufactured by Westinghouse

IN	95019	Failure of Reactor Trip Breaker to Open Because of Cutoff Valve Switch Material Lodged in the Trip Latch Mechanism
IN	95022	Hardened or Contaminated Lubricants Cause Metal-Clad Circuit Breaker Failures
IN	96024	Preconditioning of Molded-Case Circuit Breakers Before Surveillance Testing
IN	96044	Failure of Reactor Trip Breaker From Cracking of Phenolic Material in Secondary Contact Assembly
IN	96046	Zinc Plating of Hardened Metal Parts and Removal of Protective Coatings in Refurbished Circuit Breakers
IN	96050	Problems with Levering-in Devices in Westinghouse Circuit Breakers
IN	96062	Potential Failure of the Instantaneous Trip Function of General Electric RMS-9 Programmers
IN	97001	Improper Electrical Grounding Results in Simultaneous Fires in the Control Room and the Safe-Shutdown Room
IN	97069	Reactor Trip Breakers and Surveillance Testing of Auxiliary Contacts
IN	98038	Metal-Clad Circuit Breaker Maintenance Issues Identified by NRC Inspections
IN	99013	NRC Information Notice 99-13: Insights from NRC Inspection of Low and Medium-voltage Circuit Breaker Maintenance Programs
GSI	055	Issue 55: Failure of Class 1E Safety-Related Switchgear Circuit Breakers to Close on Demand (Rev. 2)

4.2.2 INPO Generic Communications (SEE-IN)

The INPO SEE-IN database was also interrogated to identify applicable generic communications. The search identified 87 LERs associated with 480Volt and 4KV circuit breakers for the period of 1984 to 2001. Most of these LERs describe the more serious events that resulted in Safety System Actuations (SSAs), SCRAMS or plant trips, LCOs, station alerts and half trips. Many of these events also produced other consequences (fatalities, injuries, fires, explosions, equipment damage, etc.). There are 230 Operating Event Reports (OEs) in the database, which INPO selected from the LERs and issued as OEs. Two of these were flagged by INPO as Significant Event Notifications (SENs), both of which deal with medium voltage 4KV breakers:

SEN-218 “Circuit Breaker Fault Results in Fire, Loss of Off-Site Power, Reactor Scram, and Severe Turbine Damage.” The breaker was a 25-year old ABB 5HK type, with the last PM performed in 1997. Refurbishment was scheduled for 2002.

SEN-221 "Circuit Breaker to Bus Connector Fault Results in a Reactor Scram and Natural Circulation Cooldown." An inadequate amount of silver on the electrical contacting surfaces caused the poor electrical connection between the 4KV breaker and the disconnect assembly.

No relevant Significant Event Reports (SERs) were issued by INPO with respect to breakers.

In 1998, INPO issued a comprehensive Significant Operating Event Report (SOER) 98-02 [29], to describe industry-wide breaker reliability problems and to issue a set of recommendations to enhance breaker maintenance. The key problems enumerated by INPO can be summarized as follows:

- Grease and lubrication problems continue to be the dominating breaker failure cause
- Ten percent of the recent breaker failures resulted in major events (trips, scrams, equipment damage, unavailability)
- About 50% of refurbished, overhauled or replacement breakers coming from the vendors experienced some form of failure after installation. Maintenance and testing did not catch many of the problems.
- Most of the breaker failures can be traced to ineffective procedures, infrequent inspections and testing, not incorporating vendor recommendations and IOE, PMs that do not enhance reliability, inadequate root cause determinations and a lack of performance trending.

The SOER recommendations are equally comprehensive and include the following key points:

- Enhance receipt inspections of spare breakers and those returned from outside shops.
- Continually improve maintenance procedures by incorporating plant and industry experience, vendor notices and recommendations.
- Provide for feedback from the maintenance crafts for as-found conditions, effectiveness of procedures, test results.
- Establish a breaker maintenance record for each important breaker to facilitate performance trending.
- Conduct comprehensive training of engineers and crafts

4.2.4 Vendor and OEM Communications

When generic breaker issues are identified by the NRC, the utility, or a vendor (OEMs such as General Electric and Westinghouse) have issued various types of communications to their clients and end users to advise them of the problems and available remedies, parts or services. These technical advisories, bulletins and service information letters are very model and vendor specific and are typically proprietary. These communications also often form the basis for plant-specific amendment and enhancement of maintenance procedures or cause the plant to perform surveys or inspections to verify the existence or absence of the problem for their installations. The applicable breaker specific vendor communications were reviewed as part of the EPRI-NMAC Breaker Maintenance Guide development and relevant recommendations have been addressed and evaluated for inclusion. When performing plant-specific LCM planning, the most recent (post 1997) vendor communications need to be identified and evaluated for applicability.

4.2.4 Codes and Standards

For low voltage breakers, some guidance is provided in the IEEE standards C37 series with respect to monitoring [10], failure investigation [11, 12], acceptance standards [32, 33] and testing [34, 35].

The NFPA 70B [50] recommended practice for electrical equipment maintenance includes in the 1998 edition a section on low voltage circuit breakers and recommended inspection, maintenance and test intervals. The document is widely adopted in the private industry and endorsed by the major industrial risk insurers.

The maintenance testing specifications for electrical power distribution equipment and systems NETA MTS-2000 [51], published by the International Electrical Testing Association (an ANSI standards organization), provides step-by-step general procedures for low voltage breakers and MCCBs.

As mentioned earlier, because of the lack of standards, some segments of the industry such as the professional electrical apparatus recyclers league (PEARL) has developed its own reconditioning standards 2000 [52]. This document provides general procedures for low and medium voltage circuit breakers.

The IEEE Yellow Book 902-1998 [53] reviews on a broad basis the maintenance, operations and safety of industrial and commercial power systems. A section on circuit breakers as well as maintenance strategies is included.

For MCCBs the current industry accepted standard maintenance and testing is the NEMA AB-4 standard [30] (1991 original issue with a 1996 revision). The original NEMA AB-2 standard was withdrawn because of its misuse for qualifying refurbished breakers. The accepted industry standard for manufacturers test acceptance is UL-489, “Molded Case Circuit Breakers and Circuit Breaker Enclosures” [31]. A comparison evaluation was performed of the NEMA AB-4 and the EPRI MCCB Maintenance Guide, as part of this sourcebook study. The comparison is presented in Table 4-11. As is evident from this comparison, an effective MCCB PM procedure needs to take the best and applicable features of both standards.

Table 4-11
MCCB Preventive Maintenance Task Comparison

Task Description	EPRI-NMAC [5] Task	NEMA AB-4 [30] Task
6.2 Test and Inspection Frequency	For Cat 2 MCCBs 5-8 years For Cat 3 or 4 MCCBs 6-12 years	Not defined in the Code
7.1. Overheating Inspection	7.1.2 Infrared Thermography of energized MCCBs	Not defined in the Code
	7.1.3 Manual Overheating Inspection (tactile-finger test)	3.2.2 Exposed face temperature check (tactile-finger touch, 3 seconds), following a 3-hour heat-up
7.2 Enclosure Inspection	7.2.3 Design Verification	3.3.2.3 Verify breaker ratings
	7.2.4 Molded case examination 1.Examine breaker surfaces for dust, soot, grease, and moisture and clean it. 2. If necessary clean the breaker 3. If necessary eliminate source of dirt, grease, moisture 4. Examine MCCB for cracks and replace if cracked	3.3.2.4 Examine breaker surfaces for dust, dirt, soot, grease, or moisture and clean it.
		3.3.2.5 Examine housing for cracks and replace if cracks are found
	7.2.5 Overheating checks 1. Check all visible components for overheating, arcing 5. Clean and dress if discoloration, pitting is minor 6. Replace parts with excessive damage	3.3.2.6 (b) If there is evidence of overheating or arcing, investigate the cause
	7.2.7 Wiring Inspection 1. Inspect visible wiring for damage and remove, repair damaged portions	3.3.2.6 Verify conductors are right size, visually check all connections are clean and secure.

Task Description	EPRI-NMAC [5] Task	NEMA AB-4 [30] Task
7.3 Mechanical Operation Inspection	7.3.2 Inspection Procedure 3. Exercise breaker manually, moving handle to On-Off positions. Minimum of three cycles is recommended. Use Ohmeter to verify breaker positions 5. Replace breakers that do not function correctly	5.2.2 Procedure 5.2.2.2 Breaker handle should operate smoothly without binding. Use ohmmeter (or similar) to verify On-Off positions.
8.0 Over-current Test	8.2 NEMA AB-4 Overload trip test to assure thermal trip unit functions correctly.	5.6 Instantaneous over-current trip test with the breaker removed from enclosure
9.0 Electrical Tests	9.1 Insulation resistance test (megger). >50Mohm is acceptable 9.2 Insulated pole resistance test (Millivolt Drop test) 9.3 Rated Hold test to verify the breaker can carry its rated current without tripping 9.4 Shunt trip test to confirm that the shunt trip will trip to open the breaker	5.3 Insulation resistance test at 500 VDC minimum. 5.4 Individual pole resistance test (Millivolt Drop test) 5.7 Rated Hold-in Test is done when the breaker is tripping under normal load 6.2 Shunt trip release test

4.2 Experience in Fossil, Industrial Applications

Operating experience with breakers in fossil power plants and industrial applications (oil and gas, petro-chemical, mining, and others) is reflected in the data collected and published by IEEE [12] as discussed earlier. Additionally, IEEE conducted a survey to determine the influence on failures caused by inadequate maintenance as a function of maintenance frequency. Included in this survey were a variety of electrical components, including circuit breakers represented largely by industrial applications other than power plants. The results are nevertheless of interest to power plants and are shown on Table 4-12. The data is self explanatory for the breakers and concludes that the breaker failures due to inadequate maintenance soar to 77.8% of all breaker failures if the maintenance frequency is more than 24 months.

European breaker data has also been reviewed in Section 4.1 above. In essence, breaker failures average to be about 0.3 to 0.5 % per year, regardless of the breaker types and applications. This is in contrast to the medium voltage breakers, which in general exhibit a higher failure rate due to their complexity and the failure consequences are most often far more severe due to the higher energy rating (voltage and amperage). There is good reason not to mix statistical data (failure rates) from low and medium voltage equipment.

Observations on breaker failures in the commercial and industrial environment include the following:

- **Failures causing operation interruption.**
  Lack of lubrication of the trip latch mechanism does not allow the breaker to reset properly. Lack of “exercising” the breaker contributes to the failure.
- **Failures during preventive maintenance testing**.
  Lack of lubrication of the trip latch mechanism does not allow the breaker to reset properly. Breaker tripping does not meet trip curve characteristics during primary injection testing. Circuit breakers with more moving parts are more prone to failures, molded case and insulated case high power circuit breakers generally have fewer moving parts.

Observations by low voltage circuit breaker reconditioning companies in regard to individual component failure include the following:

- Circuit breaker case labels are no longer legible, cracks and chips, overheating damage.
- Circuit breaker lugs show signs of cross-threads or stripped threads, signs of overheating, plating damage, improper tightness.
- Phase separators/barriers exhibit dust accumulation, chips, cracks, overheating.
- Arc chutes/extinguishers show cracks, corrosion, chips, signs of overheating, excessive deterioration or carbon buildup.
- Main and arcing contacts experience excessive deterioration, overheating, pitting, chips, and improper alignment/seating in closed position.
- Control wiring shows signs of overheating, damaged insulation, loose or defective terminal connector.
- Racking/drawout mechanism experience signs of rust and corrosion, excessive or inappropriate lubrication, missing screws/bolts/nuts/fasteners/retainers/keepers.

Primary and secondary disconnects/stabs have shown excessive or inappropriate lubrication, improper alignment, overheating, spring annealing.

Table 4-12
Percentage of Failure Caused from Inadequate
Maintenance vs. Months Since Maintained

Failure (Months since maintained)	All electrical equipment classes combined	Circuit Breakers	Motors	Open Wire	Transformers
Less than 12 months ago	7.4%	12.5%	8.8%	0%	2.9%
12–24 months ago	11.2%	19.2%	8.8%	22.2%	2.6%
More than 24 months ago	36.7%	77.8%	44.4%	38.2%	36.4%
Total	16.4%	20.8%	15.8%	30.6%	11.1%

5
GUIDANCE FOR PLANT-SPECIFIC SSC CONDITION AND PERFORMANCE ASSESSMENT

This section addresses steps number 8, 10 and 11A in the LCM planning flow chart (Figure 2-1b) and provides guidance for the plant-specific LCM planning for the LVDS. Also included in this section (section 5.4) is a compilation and description of available and useful condition or performance monitoring programs.

- In step 8, the plant-specific operating and performance history is compiled, as discussed in section 5.1 below.
- Step 10 comprises a compilation and review of the plant-specific maintenance program for breakers, leading to the establishment of a complete inventory of the current maintenance tasks and providing a basis of determining if enhancements or changes are desirable.
- In step11A, the intent is to characterize the present plant-specific physical condition and performance of the LVDS, including the breakers, and the implementation of effective preventive maintenance procedures, diagnostics and component condition monitoring. The assessment of the maintenance tasks should pay close attention to whether and how the tasks address any deviations identified in this SSC performance assessment and the SSC condition review. The deviations may be positive in that plant-specific SSC performance and conditions are superior to the industry average, in which case unnecessary or too frequent PM may be performed, or the deviations may be negative, indicating a need or opportunity for improvement. Details of the condition and performance assessments are discussed in section 5.3.

5.1 Compiling SSC Operating and Performance History

The operating and performance history and the age of the plant LVDS equipment and the breakers in particular has a major bearing on the LCM planning choices and provides the basis for the condition and performance assessment. In conjunction with the performance review, a thorough assessment of the existing equipment is of paramount importance in making realistic decisions as to what maintenance options or strategies are feasible, let alone optimal. The following are recommended steps in assembling the operating and performance history for the breakers:

- Assembling the maintenance history for the breakers, particularly the corrective maintenance actions over the last 5 years. The maintenance history may also exhibit evidence of performance concerns or unacceptable failures of other critical components, such as buses, relays, trip units and transformers.

- Trending the historic failure rates to identify any specific type of breakers that may exhibit unusual performance challenges or high failure incidents.
- Compiling and reviewing performance test results, calibrations, surveillance tests, to determine if trends exists, repetitive drift and calibration adjustment of the same equipment, current trip curves, etc.
- Thermography data showing breakers that may run abnormally high or are located in elevated temperature areas, enclosures and cubicles.
- Reviewing the as-found condition and test reports for the breakers, MCCs and cubicles to determine if the current maintenance and frequency is effective in maintaining the equipment.
- Reviewing the operating history of the specific breakers with respect to the number of operations/cycles since the last maintenance (some breakers have cycle counters), duty cycle based on estimated percentage of time the breaker is energized, frequency and number of fault interruptions or overcurrent conditions, number of racking in and racking out of the breaker. Breakers with high operating duty will experience higher wear and tear and requiring more frequent PM. The EPRI PM Basis Templates and INPO AP-913 provide some guidance as to categorizing breakers in accordance with their service duty and recommended adjustments to the PM frequency.
- Reviewing the Maintenance Rule performance parameters and trends, the system health reports, MR periodic assessments and the number of MPPFs and repetitive MPFFs for any performance weaknesses or trends, including the past and present monitoring status (A-1 and A-2), goal setting and goal monitoring and the effectiveness of corrective actions implemented.
- Reviewing the plant scram and trip history to determine the events caused by the LVDS and its components (including the plant-specific breakers that may not be directly identified with the LVDS, or may belong to other systems). For those events caused by the LVDS, the lost power generation due to forced or unforced plant trips, scrams, extended outages, partial power operation or hot standby conditions governs the historical cost of LVDS failures. The results provide a basis for projecting future performance (negative if performance is declining and additional preventive action is not implemented or positive if new PM or PdM tools are applied or equipment enhancements/upgrades are contemplated) in the LCM planning.
- A review of the spare parts usage and remaining parts inventory to provide an indication of expected versus actual use and associated failure frequency.
- A review of information on replacements and equipment upgrades already made or planned for the near future.
- A review of design changes and technology upgrades that have been instituted.
- Some plants have recently implemented a Maintenance Condition Feedback program for the breakers to record the as-found equipment conditions. In this program, the crafts team performing the preventive or corrective maintenance is required to formally document the as-found conditions of the equipment. The documentation is done with a simple form attached to the work order and showing five possible as-found conditions. The crafts person indicates

with an “X” the most applicable condition and provides additional notes in case an abnormal condition is encountered. The five categories for the equipment conditions scale are:

- Like New
- Better than Expected
- Expected
- Degraded
- Severely degraded

The information will facilitate an adjustment to the PM tasks or frequency, commensurate with the equipment condition expectation, considering its age and service environment. The data also provides the intelligence to perform additional inspections, sampling or testing of equipment with similar characteristics and for avoiding potential failures. Compilation and review of the data provides a major input to the current condition assessment of the breakers.

5.2 Review of Current Maintenance Activities

5.2.1 Compiling Maintenance History

To develop a clear picture of past LVDS and breaker performance from which projections can be generated, a thorough review of the maintenance history is needed. This maintenance history is captured at most plants in Work Orders, often managed by a database. Work Orders are written to execute preventive maintenance or corrective maintenance and to implement other activities, such as overhauls, surveillance tests, design changes, replacements or upgrades.

The most important Work Orders are those implementing corrective actions as a result of problems, replacements due to obsolescence and design changes. They often contain information concerning the root cause, whether repetitive problems were involved, the cost and man-hours spent in the corrective action, and the reason why the problem was not detected in the incipient stages. This information is used to identify additional preventive maintenance (PM) or predictive maintenance (PdM) activities, potential enhancements to the current maintenance program and/or the need for replacement, redesign or upgrades. The basic premise is that performance can only be improved by preventing problems (having the ability to detect incipient failure and degradation before full loss of function occurs) and therefore it is important to identify the causes of the problems and to determine the actions that could have prevented the failure.

The Work Order review also provides detailed information as to the annual frequency of occurrence of problems and failures presently experienced by the LVDS and its associated breakers. These problem occurrence rates are one of the most important inputs for calculating the costs of corrective maintenance and failures (due to lost power production, required spare parts, regulatory risks, EPIX reporting, MR A-1 monitoring, etc.) when performing economic modeling of LCM alternatives.

The Work Order review can also be used to trend the annual corrective and preventive maintenance activities over the past several years to see if the rate of occurrence of problems is increasing or decreasing and if the ratio of corrective to preventive Work Orders and their implementation costs are changing. An effective PM program should show a gradual decrease of corrective Work Orders and corrective activity costs. The data can lead to the identification of additional corrective or preventive actions that may be justified to effect a positive change. These actions would be part of the Alternative LCM plans to be evaluated.

5.2.2 Inventory of Current Maintenance Activities

Once the plant-specific maintenance history has been compiled, the current maintenance activities need to be identified. When using the word "Maintenance" in LCM planning, the activities associated with the system include preventive, predictive and corrective actions, whether required by Regulations (testing, inspection, surveillance, walkdown, monitoring, sampling, EQ, etc.), by applicable Codes (IEEE, NFPA, State requirements, local requirements), by the insurance carrier, or by plant procedures, programs, or policies. Collecting the associated activity parameters, such as the annual frequency of the task, the number of components to which the activity is applied (i.e. the number of breakers covered by a specific PM), labor hours required to perform the activity (on a component basis), indirect labor associated with the activity and the material costs, will provide the key input to developing a base case for LCM planning. This base case is not only important to create an inventory of the current activities and the total annual maintenance cost for the system, but it provides a benchmark for comparison to industry practice and a basis from which the need for additional activities, enhancements or task reduction opportunities can be judged. A convenient way to assemble this information is illustrated in the sample given in Table 7-1.

5.3 Conducting the Condition and Performance Assessment

The generic performance data and information presented in the preceding sections can be used for plant-specific LCM planning in many ways. In particular, for plants not having a large data basis of experience, the generic data provides a basis for a sound component-specific PM program. Furthermore, the data may be used for comparison trending or projecting performance or failure data into the future when attempting long-term LCM planning. If the plant is of recent vintage, the failure data provides an indication of the types of failures to be expected as the plant ages and shows potential precursors of problems to be anticipated. Lastly and most importantly, the benchmarking of plant-specific data against generic (or industry) performance data for low voltage electrical distribution systems and the breakers in particular, provides LCM planners with information with which to focus on areas in which there are significant opportunities to achieve economic and technical improvements. The steps involved in plant-specific performance and condition assessment (including benchmarking) can be summarized as follows:

- At the system level, benchmark the LVDS contribution to the total plant lost power generation against the industry PWR/BWR specific average (Table 4-2). This will provide a preliminary assessment as to the current and past plant system health and indicate if the plant LVDS performs at, above or below industry standards with respect to lost power generation and associated impact on plant safety. The results of this benchmarking provide a basis for projecting future trends (negative if performance is declining and additional preventive action is not implemented or positive if new PM or PdM tools are applied or equipment enhancements/upgrades are contemplated) in the LCM planning.

- At the breaker level, a review should be conducted of all the plant transients, power reduction events, and scrams since plant operation began. This review should focus on the cause of the event, the principal systems or components involved and whether the LVDS or the breakers were a direct or indirect contributor to the event. As discussed earlier, many plant trips may be associated with a certain plant system, however, the actual failed component causing the trip might be a breaker assigned to that system and not the LVDS, so it is important to review the trip causes to the component level to identify the true culprit. The attributed events and the associated lost power generation hours are tabulated and the percentage contribution of the LVDS and the breakers to the total is computed in total MWhrs and percent. This total can be compared to the generic LVDS lost power contribution (e.g., 3.64% for BWRs and 3.17% for PWRs, Table 4-2) to arrive at a plant-specific benchmark indicating the relative performance of the LVDS and breakers and to determine if dramatic enhancements are justified or possible. The plant-specific LVDS contribution to lost power generation should be used in the economic modeling of LCM alternatives, by applying a factor of increase or decrease to reflect the projected impact of the maintenance plan associated with the specific alternative LCM plan. Additional guidance is provided in Section 8 and in the overview report [3].
- At the component level, compare plant-specific critical and non-critical breaker failure rates to those discussed in Section 4.1 and Table 4-1 and Table 4-3 to diagnose and identify potentially unacceptable component performance. If this is not possible, start a comprehensive breaker performance monitoring program and review in detail the past 5 years of corrective breaker work orders to resurrect the failure history.
- Compare the EPRI SysMon LVDS performance parameters (Figure 4-12, Figure 4-13, Figure 4-14) to the plant-specific parameters established under the Maintenance Rule to verify that the plant parameters are reasonable and representative and are appropriate to effectively measure system performance and are able to detect degrading conditions of the systems and the breakers. Review the cross-system MPFF and repetitive MPFF monitoring of breakers to detect changing breaker reliability without being masked by system performance indicators. For some plants, a cross system breaker assessment may be required to perform a meaningful performance assessment for the breakers.
- A detailed review of the current maintenance procedures to assure that industry operating experience has been addressed and applied. Maintenance procedures with approval dates that are more than 4 years out-of-date are likely outdated and probably do not adequately incorporate latest industry information.
- Compare the plant-specific breaker maintenance procedures and tasks against the industry recommendations (Table 4-4 to Table 4-9 and Table 4-11 for MCCBs) to identify opportunities for addition or deletion of PM or PdM activities and adjustments to the associated task intervals. If the breaker performance has been exceeding the industry standards and failure rates are below average, changes to the breaker PM program should be implemented cautiously and with good reason. On the other hand, if the breaker performance measurably lags industry average and the plant’s breaker PM program significantly deviates from the industry recommendations, review the justification for these deviations critically to identify causes and opportunities for enhancement.
- Review the corrective work orders and root cause evaluations of breaker failures to determine if the failure causes are commensurate with the industry experience shown in

Figure 4-6 and Figure 4-7. This review could detect an abnormally high rate of human errors, indicating a need for crafts training or procedure enhancement, or frequent repetitive failures indicating symptomatic fixes and ineffective root cause determination or corrective action.

- Similarly, from the corrective work order review, tabulate the failure detection modes for the failed breakers to determine if the plant's preventive and predictive maintenance program is capable of detecting failed breakers prior to a real demand causing a loss of function. Figure 4-8 shows an industry average of about 48% success in pre-demand detection (through tests and inspections).
- To assure that the long term maintenance plans include a thorough and critical review of aging and obsolescence concerns, establish a detailed inventory and matrix of all the plant breakers, their failure rates, projected spare parts use, potential replacement models or refurbishment kits, current spare parts inventory, exchange or reuse opportunities and reliable suppliers of parts, services and replacements.
- Identification of predictive maintenance tools and procedures and their application frequency. Implementation of these PdM tools makes PM more effective and proactive and often justifies a reduction of PM frequency and attributes. Thermography, regular walkdowns, as-found condition monitoring, surveillance testing and equipment exercising are some of the more effective PdM tools.
- A condition assessment also entails reviewing the most recent results or documents from overhauls, refurbishments, calibrations, surveillance tests and diagnostics to arrive at a comprehensive picture of the current condition of the LVDS equipment. From the SSC condition review, a plant-specific assessment can be made as to whether equipment can meet expectations and requirements over the remaining operating period of the plant (including license renewal) and may lead to the identification of equipment to be targeted for replacement or upgrading.

A critical review of the aging management summary Table 6-1 to determine if relevant plant-specific aging management programs have been in use and are effective. Deficiencies may lead to identification of program changes or enhancements.

5.4 Condition and Performance Monitoring Technologies

A review was conducted of industry operating experience and practices to identify available and useful condition and performance monitoring technologies that may be applied to LVDS breakers. When applied, these tests or maintenance tasks may provide additional information of the component condition, facilitate detection and identification of incipient failures, detect the onset of age related or operational degradation, determine operational readiness, verify functional performance, provide diagnostic intelligence of malfunction or uncover existing failures of run-to-failure components. The following are the most common preventive and predictive condition and performance monitoring programs.

5.4.1 System Surveillance Testing

Condition monitoring of the LVDS consists primarily of the surveillance testing required by the plant's Technical Specifications as applied to various safety-related systems. When an Engineered Safety Feature (ESF) is functionally tested, the initiation circuitry and controls as well as the power supplies (including the breakers, buses, transformers, switches, relays, etc) are energized and tested. The frequency of these tests varies from system to system and plant to plant, but generally the tests are done monthly (RPS and EDG) or quarterly, with few exceptions. Redundant trains and active components are tested separately and individually. Many of the safety-related breaker failures are detected during these tests (37% for breakers and 34% for MCCBs per Figure 4-8 and Figure 4-10 respectively). Because the surveillance tests are go-no-go tests, degradation or incipient failure is not detected unless the component fails and causes a loss of system function. The only value for LCM planning in these tests is a source for failure data of breakers that can be trended over time to look for emerging problems.

5.4.2 Thermography

Infrared thermography is directed mainly at detecting loose electrical connections, strong local eddy current heating, frictional heating, abnormal heat loss or heat transfer and proper operation of transformers, coils, fuses, buses and similar passive components. Thermography needs to be performed while the equipment is operating and/or is energized and electrical panel doors are open. Thermographic surveys should be performed during periods of maximum possible loading but no less than 40 percent of rated load.

Thermography will detect increases in temperature that affect the breaker if it is accessible, and those that ultimately affect the whole cubicle, as well as accessible areas of the buswork. Typically such temperature increases will be associated with main current carrying components and will be caused by loose or contaminated connections, or primary contacts that are out-of-adjustment, pitted or corroded, or which have damaged plating.

The normal heating effect of the main current in energized breakers may be allowed for by comparing the breaker or cubicle temperature with that of neighboring breakers carrying similar loads or by trending the temperature readings of a particular unit over time, or by comparing the thermal image to a "Baseline Signature." Additionally, a temperature comparison of all three phases should be made while accounting for the potential effects of phase current unbalance. The recommended period for thermographic inspection is 1 year because of the quick, non-intrusive nature of the task and the ease with which many adjacent cubicles can be surveyed at one time and location. This task interval is significantly shorter than the times to first failure anticipated from breaker failure causes, and results in thermography being an effective condition monitoring task for those failure causes. Consideration should be given to extending thermographic scan intervals taking into account breaker loading conditions and previous thermographic histories [14].

Breaker and Cubicle Thermographic Scan should include the inspection for unusual heating of the circuit breaker and truck, cubicle, and bus work, that is not commensurate with local and historical trends.

5.4.3 Breaker Failure Trending Program

A typical plant has between 1500 and 2500 breakers, switchgear and MCCBs at voltages from 125 VAC/VDC to 4KV and higher. The equipment is distributed over the entire plant and provides service to many systems. There is a great diversity of component models and types supplied by a host of manufacturers, often numbering more than 100 different varieties. To maintain an overview and a measure for performance and failure rates of these devices, a comprehensive breaker failure trending program has been recommended by INPO during various plant assist visits. Such a program might consist of the following basic elements:

- Establish a plant wide inventory of the breakers, grouped and sub-grouped by logic parameters (safety, non-safety, voltage rating, manufacturer, model, accessories, covered by the same PM, etc)
- Establish individual or breaker group dossiers of operating and maintenance history, spare parts use, refurbishment kits, acceptable greases, tools required for PM and overhaul.
- Based on the past corrective work orders for each breaker group, identify the breaker failures, causes and failure detection. This will provide the needed input to the Maintenance Rule to identify repetitive failures of an identical breaker under the same cause.
- Start trending the data collected over time (for individual groups, voltage ratings and all breakers) to determine long-term performance trends. These trends should be able to detect age related performance degradation, measure effectiveness of PM, provide a basis for adjustment of PM intervals and overhauls and indicate approaching end-of-life realities.
- Additional parameters needed for comprehensive LCM planning include the lost power production associated with breaker failures and the occurrence of other failure consequences (safety and cost).

The trending of breaker failures would also provide intelligence for spare breaker/parts procurement, warehouse inventory management and obsolescence management of breakers.

5.4.4 Time Directed Equipment Qualification

Some plants, and more likely PWRs, have electrical distribution equipment and breakers situated in a normally harsh environment, including the containment. Under these conditions, the breakers may not last the original 40-year plant life. Depending on the plant-specific conditions, breakers may be qualified for less than 40 years, to anywhere between 7 to 20 years and require replacement at the end of their qualified life. Not all the breaker components are generally affected and typically only the greases and non-metallic parts (plastics, Teflon, synthetic and natural rubber, some wiring insulations) have a limited lifetime. Plants may be replacing the entire breaker (as is the case with MCCBs), or may remove the breaker from its position to install the replacement kit parts. Usually this is done in conjunction with a breaker overhaul and requires post maintenance acceptance testing after the breaker has been reinstalled in its bucket.

5.4.5 Airborne Acoustic Testing

Airborne acoustic testing has been recommended by the EPRI Maintenance and Diagnostics Center for medium and high voltage switchgear. This acoustic emission test will detect discharges such as arcing, tracking, and corona from all high voltage and high current components. Application to low voltage switchgear is best performed with an industrial acoustic probe, but has provided disappointing results except for electro mechanical relays.

5.4.6 Other Performance and Condition Monitoring Tests

Breaker performance and condition tests performed as part of the breaker PM or overhaul may provide insights to poorly performing subcomponents and parts, including aging of grease, wear, spring relaxation, contact erosion/corrosion, electrical degradation, binding, etc. The tests typically performed, include (as applicable to the various breaker types):

- **Recording of Cycle Counter Readings** provides an indication of the breaker cyclic duty.
- **Reduced Control Voltage Testing** verifies the breaker's ability to operate at the lowest design basis voltage. The test may provide a basis for additional corrective maintenance or further adjustments and is not considered a predictive tool.
- **Main Contact Resistance Test** verifies that the contacts and associated electrical connections are clean and resistance is minimized to avoid internal heating.
- **Manual and Electrical Operations Check** ensures proper operation of all mechanical and electrical breaker functions.
- **Anti-Pump Operational Check ensures that** the circuit breaker is not prevented from reclosing if a close input is maintained during a trip free position.
- **Contact Simultaneous Make and Pressure Check** tests for minimal heat and electrical arcing under load conditions and ensures that a good electrical connection exists between the moving and stationary contacts and that all contacts close simultaneously and achieve proper contact pressure.
- **Trip Load Measurement** verifies that the breaker will trip when required by the control circuit or during an overcurrent or undervoltage condition. The trip load is measured with a force gauge to produce a force as specified by the OEM.
- **Bell Alarm Test** verifies the correct operation of the bell alarm so the cause of an unexpected trip can be determined (overcurrent or control circuit).
- **Insulation Resistance Test** measures the insulation resistance of the line-to-load with breaker open, phase-to-ground with breaker closed and phase-to-phase with breaker closed. This test ensures that no grounds exist and wiring insulation is satisfactory.
- **Overcurrent Trip Device (OCTD) Testing** verifies proper operation of the trip device (mechanical, electro-mechanical or solid state). This test compares the actual trip characteristics to the OEM provided overcurrent trip unit time-current curves. Note that the overload trip device of the electro-mechanical type is not designed to be cycled frequently. The bimetallic strip and contacts have very long life provided they are not over-stressed.

However, long exposure to overcurrent or too frequent testing of these devices results in a shift in trip set point that may only be revealed by a timed-current test.

- **Circuit Breaker Timing and Travel Analysis** provides some indication of specific circuit breaker subcomponent conditions, but does not provide a comprehensive assessment of the overall breaker condition. The timing test is useful to evaluate response time with respect to manufactures timing specifications, to detect potential mechanical binding and unusual friction. It is noted that timing tests are not recommended by the OEMs as a periodic routine PM. Travel analysis is primarily performed on medium and high voltage circuit breakers.
- **Primary and secondary injection trip unit calibration** The first method involves high current injection on the circuit breaker to simulate an overload or fault. This test generally requires the circuit breaker to be removed from the cell. Secondary injection can be performed on circuit breakers equipped with solid state trip logic. Generally an OEM test kit is required.

6
GENERIC AGING AND OBSOLESENCE ASSESSMENT

This section addresses the steps numbered 11B and 11C in the LCM planning flowchart (Figure 2-1b). Its intent is to help characterize the aging of passive SSCs, the wear-out of active components, and the obsolescence of SSCs. This characterization will serve both to help address the need for and timing of the replacement of LVDS equipment and breakers in particular in the LCM planning process and to identify potential environmental or service conditions that affect the rate of degradation or may require special plant-specific attention.

6.1 Aging Mechanism Review

An aging management review is integral to LCM maintenance planning. Three documents are particularly pertinent to such a review: The Aging Management Program for Electrical Components, summarized in the NRC's Generic Lessons Learned report (GALL) [40], the EPRI Electrical Tools Handbook [39], both of which address only passive electrical components (buses, cables, connectors, insulators and conductors) under the License Renewal Rule [41], and the EPRI PM Basis for Low Voltage Switchgear [14] which addresses active components such as breakers.

With respect to License Renewal, breakers are not specifically addressed and do not require an aging assessment (they are considered active and are monitored under the Maintenance Rule). Breakers that are covered under the EQ program for harsh environments will require reevaluation under the License Renewal Rule to qualify for the extended service period to 60 years of operation. The environmental re-qualification process is still under development and may include re-qualification by testing, by analysis (such as Arrhenius) using actual environmental profiles from the plant, or by replacement at the end of the current qualified life.

The USNRC as part of their Nuclear Plant Aging Research Program (NPAR) extensively investigated aging of circuit breakers, relays, switchgear, MCCBs and specifically the Westinghouse DS reactor trip breakers [42, 43, 44, 45]. Much of the data and most of the recommendations from these references have been integrated into the EPRI Breaker Maintenance Guides; however, specific aging information was reviewed and extracted from these reports with respect to aging mechanisms, aging effects, effective aging management actions and component life expectancy and has been incorporated into the aging matrix shown in Table 6-1.

Under a collaborative agreement between EPRI and the US Department of Energy, the Sandia National Laboratory developed and published a series of Aging Management Guides (AMGs), of which two are relevant to the aging assessment of electrical equipment, the AMG for Motor Control Centers [46] and the AMG for Switchgear [47], both of which provide input to the identification of plausible aging mechanisms and effects, as well as recommended aging management methods.

Table 6-1 provides a summary of the principal aging effects and mechanisms, the associated effective aging management methods and the specific reference, as applicable. The following are descriptions and clarifications for the column headings in the table:

- Aging Effects are the manifestations of aging as observed in the field
- Aging Mechanisms are the possible causes of the observed aging effects
- Typical Aging Management Programs consist of those preventive and predictive actions that are able to detect and diagnose incipient aging and degradation before failure occurs.

The following quote was extracted from one of the EPRI Breaker Maintenance Guides [19] to illustrate the principal aging and maintenance concern with breakers:

"Dried and dirt contaminated lubricant was the predominant degradation mechanism and was common to all breakers. It is also the most insidious because it is gradual, difficult to detect, and constitutes the primary failure cause for both electrical and mechanical components. It is typically detected when an electrical component, such as a UV coil or shunt trip coil, fails or the breaker malfunctions. The only effective method to remove the degraded lubricant is to disassemble the operating mechanism to access to the bearings, shaft and pins. This is the typical work associated with a breaker overhaul. The average age of operating mechanism lubricant failure, according to the failure reports, is 8.8 years. It would appear that breaker overhaul should be undertaken in a six to ten year time period."

The aging mechanisms and aging effects discussed in Table 6-1 reflect the normally benign environment in which the major components are located; that is, the reactor, auxiliary or turbine building in the plant. The environmental conditions for the equipment are normally controlled and include protection against external environments such as weather, UV light, exposure to rain or water and temperature extremes. The location of the equipment is such that easy maintenance access is assured and radiation is commensurate with normal access provisions. Some equipment, such as breakers, may also be installed in unheated plant areas or areas with elevated temperatures (containment, steam tunnel, feed pump area). In this case, a plant-specific aging evaluation may be required. Caution is also appropriate with equipment that is located outdoors with respect to functional concerns affected by freezing, viscosity change for lubricants, moisture intrusion and condensation, dust and rodent damage. In contrast to the external environment the local conditions for breakers situated in closed cubicles may be significantly different from those in the general surroundings. Temperatures can reach 30 to 40 degrees F above room temperature in cubicles that contain energized equipment (transformers, coils, resistors, etc). The elevated temperature leads to premature aging of susceptible materials, such as grease, seals, caulk, plastics and cable/wiring insulation.

Table 6-1
Aging Management Summary for Electrical Components

Component or Part	Material(s)	Aging Effects	Aging Mechanism	Typical Aging Management Program	Reference No.
Breakers					
Operating Mechanism	Metallic components	Shattering, looseness, lack of contact, loose parts	Wear, impact, shock and rebound, spring relaxation	Surveillance testing Periodic PM Visual inspection, Overhaul	[14], [42]
		Binding	Corrosion, pitting, dust contamination, degraded lubricants, mechanical interference	Cleaning and lubrication Surveillance testing Periodic PM Visual inspection, Overhaul	[14], [42]
		Cracking, distortion	Cycle fatigue, mechanical damage	Visual inspection, Overhaul	[42], [46]
	Non-Metallic components	Cracking, distortion, discoloration, chipping	Embrittlement, overheating, fatigue	Thermography, Visual inspection, Overhaul	[46], [47]
		Binding	Aged or defective lubricants	Cleaning and lubrication	[14], [46]
Racking Mechanism	Steel	Binding	Corrosion, lack of lubrication, inactivity	Periodic PM Cleaning and lubrication	[14]
		Loose/missing parts	Vibration, cycling	Visual inspection, Overhaul	Misc.
		Distortion	Physical damage, handling	Visual inspection	[19]
Main and Arcing Contacts	Copper, silver	Arcing, loss of contact	Corrosion, pitting, excessive cycling, overheating	Thermography, Surveillance testing Periodic PM Visual inspection, Overhaul	[14], [46]

Component or Part	Material(s)	Aging Effects	Aging Mechanism	Typical Aging Management Program	Reference No.
Disconnects/Stabs	Copper, Brass, Silver	Arcing, Loss of contact	Lack of or excessive lubrication, spring annealing, poor alignment	Thermography, Surveillance testing Periodic PM Visual inspection, Overhaul	Misc.
Arc Chutes	Asbestos, FRP	Loss of Material, burning/fire	Erosion, carbon soot deposition	Periodic PM Replacement of arc chutes/plates	[42], [14]
Insulation	Non-metallic	Loss of insulation, discoloration, arcing, short circuit, melting	Overheating, embrittlement, chafing, physical damage	Thermography, Surveillance testing Periodic PM Visual inspection, Overhaul	[14], [46]
Cable and Wiring (Conductors)	Copper	Cracking, melting, loss of material, loss of contact	Moisture intrusion, corrosion, loose connections	Surveillance testing, Thermography Periodic PM Visual inspection, Overhaul	[40], [46]
Housing	Metal or Plastic	Discoloration, cracking, splitting, loss of label	Overheating, vibration, cycling	Visual inspection	
Overcurrent Trip Device	Various	Failed test	Out of calibration, drift	Testing	[19]
Current and Potential Transformers	Various	Discoloration, melting, burning, short circuit	Insulation failure, overheating	Visual inspection, Testing	[47]
Shunt Trip Device	Various	Failed test, binding	Lack of lubrication, coil overheating	Visual inspection, lubrication, testing	[47]
UV Trip Device	Various	Binding	Wear, friction, constant coil energization	Thermography, Periodic PM Visual inspection, Overhaul	[47]
MCCBs					

Component or Part	Material(s)	Aging Effects	Aging Mechanism	Typical Aging Management Program	Reference No.
Operating Mechanism	Various	Binding, sticking of mechanism	Lubrication failure	Testing of breaker, clean, inspect, cycle	[46]
Current trip device, contacts, lugs	Various	Loss of contact, contact erosion, discoloration	Loose connections, overheating	Thermography Testing of breaker, clean, inspect, cycle	[46]
Housing	Plastic	Cracking, splitting, discoloration, melting	Overheating, short circuit, premature aging	Thermography Clean, inspect breaker	
Breakers					
Operating Mechanism	Metallic components	Shattering, looseness, lack of contact, loose parts	Wear, impact, shock and rebound, spring relaxation	Surveillance testing Periodic PM Visual inspection, Overhaul	[14], [42]
		Binding	Corrosion, pitting, dust contamination, degraded lubricants, mechanical interference	Cleaning and lubrication Surveillance testing Periodic PM Visual inspection, Overhaul	[14], [42]
		Cracking, distortion	Cycle fatigue, mechanical damage	Visual inspection, Overhaul	[42], [46]
	Non-Metallic components	Cracking, distortion, discoloration, chipping	Embrittlement, overheating, fatigue	Thermography, Visual inspection, Overhaul	[46], [47]
		Binding	Aged or defective lubricants	Cleaning and lubrication	[14], [46]
Racking Mechanism	Steel	Binding	Corrosion, lack of lubrication, inactivity	Periodic PM Cleaning and lubrication	[14]

Component or Part	Material(s)	Aging Effects	Aging Mechanism	Typical Aging Management Program	Reference No.
		Loose/missing parts	Vibration, cycling	Visual inspection, Overhaul	Misc.
		Distortion	Physical damage, handling	Visual inspection	[19]
Main and Arcing Contacts	Copper, silver	Arcing, loss of contact	Corrosion, pitting, excessive cycling, overheating	Thermography, Surveillance testing Periodic PM Visual inspection, Overhaul	[14], [46]
Disconnects/Stabs	Copper, Brass, Silver	Arcing, Loss of contact	Lack of or excessive lubrication, spring annealing, poor alignment	Thermography, Surveillance testing Periodic PM Visual inspection, Overhaul	Misc.
Arc Chutes	Asbestos, FRP	Loss of Material, burning/fire	Erosion, carbon soot deposition	Periodic PM Replacement of arc chutes/plates	[42], [14]
Insulation	Non-metallic	Loss of insulation, discoloration, arcing, short circuit, melting	Overheating, embrittlement, chafing, physical damage	Thermography, Surveillance testing Periodic PM Visual inspection, Overhaul	[14], [46]
Cable and Wiring (Conductors)	Copper	Cracking, melting, loss of material, loss of contact	Moisture intrusion, corrosion, loose connections	Surveillance testing, Thermography Periodic PM Visual inspection, Overhaul	[40], [46]
Housing	Metal or Plastic	Discoloration, cracking, splitting, loss of label	Overheating, vibration, cycling	Visual inspection	
Overcurrent Trip Device	Various	Failed test	Out of calibration, drift	Testing	[19]
Current and Potential Transformers	Various	Discoloration, melting, burning, short circuit	Insulation failure, overheating	Visual inspection, Testing	[47]

Component or Part	Material(s)	Aging Effects	Aging Mechanism	Typical Aging Management Program	Reference No.
Transformers		burning, short circuit	overheating		
Shunt Trip Device	Various	Failed test, binding	Lack of lubrication, coil overheating	Visual inspection, lubrication, testing	[47]
UV Trip Device	Various	Binding	Wear, friction, constant coil energization	Thermography, Periodic PM Visual inspection, Overhaul	[47]
MCCBs					
Operating Mechanism	Various	Binding, sticking of mechanism	Lubrication failure	Testing of breaker, clean, inspect, cycle	[46]
Current trip device, contacts, lugs	Various	Loss of contact, contact erosion, discoloration	Loose connections, overheating	Thermography Testing of breaker, clean, inspect, cycle	[46]
Housing	Plastic	Cracking, splitting, discoloration, melting	Overheating, short circuit, premature aging	Thermography Clean, inspect breaker	

6.1.1 Expected Lifetimes of Breakers

In addition to long-term aging of passive components, the active breakers within the LVDS are susceptible to wear or degradation, which must be addressed by routine preventive maintenance including overhaul and component replacement. Typical failure free life expectancies for breakers and breaker subcomponents are presented in Table 6-2 together with information on degradation influence and cause.

When manufacturers of MCCBs are asked to define an operating life for the breakers, they generally hesitate and caution that the MCCB life depends largely on the operating environment, cyclic and service duty including frequency of testing, and preventive maintenance programs applied. The life of a circuit breaker is largely limited by the number of cycles it performs and the interrupting current it is subjected to.

Table 6-2
Useful Life of Breakers and Breaker Components

Component	Degradation Mechanism	Degradation Influence	Failure Free Life Expectancy (years)*
Breakers-Overall	Wear, Corrosion, Aging	Cycling, Environment	25 to 30 years or < 12000 cycles
Switchgear, 4KV	Wear, Corrosion, Aging	Cycling, Environment	25 to 40 years [48]
Grease	Hardening, evaporation	Heat, dust, inactivity	6 to 10 years
Moving parts, pins, springs, latches, cams	Wear, contamination, corrosion, pitting, binding, loose parts	High duty cycles, heat, vibration	8 to 12 years < 4000 cycles 6 to 10 years [20]
Main Contacts	Corrosion, Arcing, pitting	Inactivity, lack of lubrication	< 3 years for high cycle <10 years for low cycle
Insulation	Aging, embrittlement	Heat, contamination	> 10 years
Arc chutes	Cracking	High cycling	15-20 years [20]
OCTD (E/M)	Seal failure	Heat, degradation	10-12 years [20]
Reactor Trip Breaker W- DS-416	Various	Cycling	~20 years [42] < 10000 cycles
MCCBs	Binding, Sticking	Grease degradation	12 to 15 years

*These values are indicative and are given for planning purposes only. The wide range of equipment types used and maintenance practices followed make the provision of more precise data difficult.

6.2 Technical Obsolescence

Many systems within a nuclear power plant (and in particular those with electronic instrumentation and electrical devices) are susceptible to technical obsolescence. In LCM maintenance planning one should be aware that these systems or components within them may have to be replaced because of the unavailability of spare parts, overhaul kits or unavailability of refurbishment services. For breakers in particular, obsolescence provides unique challenges that must be addressed and accounted for when contemplating replacements as an LCM Alternative. These challenges include:

- Discontinuation of manufacture of old types of breakers, because the market has disappeared and phasing out of unacceptable materials (asbestos, PCB oils, lead paint, mercury, etc)
- The original manufacturer (OEM) has gone out of business
- The useful lifetime of most breakers is between 25 and 40 years, forcing replacement in the license renewal period.
- Replacement breakers and spare parts are more and more difficult to maintain and are aging in the warehouse (grease, oil seals, lubricants, cable insulation, rubber/plastic parts)
- Overhaul kits for old breakers are disappearing from the market
- Refurbishment contractors are not always providing quality work, decreasing breaker reliability
- Reusing safety-related breakers that have been replaced by new models in non-safety service decreases the reliability of these breakers required for important power production service.
- Replacing breakers with new models or of different manufacture leads to substantial interface engineering to address electrical compatibility, mechanical form fit and function assurance and physical modification of the enclosure (mounting brackets, stabs, door cutouts, handle fit, rewiring, racking tray, etc).
- Updating of engineering documents, databases, drawings, diagrams, procedures for testing and maintenance, training of crafts and re-labeling of equipment are additional tasks that are associated with breaker replacement
- For safety-related functions, new breaker installations must meet environmental and seismic qualification requirements.
- Breakers that require auxiliary devices (shunt trip, OCTD, UV trip, etc) often require these auxiliaries to be upgraded to newer technology (solid state).
- Replacement breakers usually require installation during an outage and even then cause the loss of an entire bus that may have an impact on normal outage schedules
- Multilevel protective device coordination is difficult to achieve with older circuit breaker trip units, including some of the early solid state devices.

To ascertain whether a given system or component is susceptible to technical obsolescence, the evaluation method provided in Table 2-2 of the Life Cycle Management Sourcebook Overview report [3] can be applied as a first step. Exercising this table for the LVDS makes it clear that technical obsolescence is a major problem for breakers. Table 6-3 provides an example of an obsolescence assessment for an outdated breaker model, using a GE AK-25, and listed in Table 3-1 as Obsolescence Category 2. The criteria given in the Overview Report [3] are as follows:

- Total Score is < 6.0, RED and the SSC obsolescence is serious. Potential options to deal with obsolescence and contingency planning should be identified. Guidance on the modeling, timing and costs of these contingencies and the associated risks should be provided.
- Total Score is between 6.0 and 10.0, YELLOW and the SSC may have longer term concerns for obsolescence. Contingency planning and options should be considered.
- Total Score is > 10, GREEN and the SSC is not likely affected by obsolescence.

Table 6-3
Example Breaker Obsolescence Assessment

	Technical Obsolescence Evaluation Criteria	SCORE	YES
1	Is the SSC still being manufactured and will it be available for at least the next five years?	5.0	
2	Is there more than one supplier for the SSC for the foreseeable future?	3.0	
3	Can the plant or outside suppliers manufacture the SSC in a reasonable time (within a refueling outage)?	3.0	
4	Are there other sources or contingencies (from other plants, shared inventory, stock-piled parts, refurbishments, secondary suppliers, imitation parts, commercial dedications, etc) available in case of emergency?	3.0	3.0
5	Is the SSC frequency of failure/year times the number of the SSCs in the plant times the remaining operating life (in years) equal or lower than the number of stocked SSCs in the warehouse?	3.0	
6	Can the spare part inventory be maintained for at least the next five years?	3.0	3.0
7	Is the SSC immune to significant aging degradation?	1.0	
8	Can newer designs, technology, concepts be readily integrated with the existing configuration (hardware-software, digital-analog, solid-state, miniaturized electronics, smart components, etc)?	3.0	
9	Is technical upgrading desirable, commensurate with safety and cost effective?	3.0	
	Total Obsolescence Score		6.0

As can be seen from the example, the GE AK breaker being no longer produced, but retaining spare parts availability, scores a total of 6.0 and is considered a borderline yellow, just avoiding the red condition. This is an example of a component requiring near term contingency action and the results for the other breakers of Obsolescence Category 2 of Table 3-1 would be similar. While this process only provides a quick and quantitative method to assign the component an obsolescence priority, the yellow and red conditions should be targeted for a more in-depth obsolescence study using other tools, such as EPRI-LITE [49].

The approaching obsolescence of breakers, including MCCBs, is an industry-wide problem facing the nuclear power industry within the next five to ten years. In view of this situation, the LCM planning Alternatives discussed in the following section will focus on the obsolescence issues and provide guidance in contingency planning.

7
GENERIC ALTERNATIVE LCM PLANS

This section addresses step numbers 12 through 17 in the LCM planning flowchart (Figure 2-1b). The EPRI LCM Demonstration project report [2] summarizes Alternative LCM Plans as follows: *"Following the assessment of aging and reliability, potential alternative LCM plans should be identified. The objective here should be to explore whether there are potentially better ways of addressing the aging management of the SSC. These inputs can come from plant staff, but input should also be solicited from outside experts and industry benchmarking projects."*

The following guidance for these steps includes the identification of possible plant operating life strategies and the development of Alternative LCM Plans that are compatible with or integral to the strategies identified. Also provided is a hypothetical illustration of alternative LCM plans (for breakers) with the attendant discussions of the logic for building the alternatives and the derivation of assumptions.

7.1 Plant Operating Strategies and Types of LCM Planning Alternatives

The determination of LCM planning alternatives will be driven in large part by the plant operating strategies that, implicitly or explicitly, are being followed or evaluated and the current reliability performance of the LVDS and the plant breakers. Accordingly, the set of LCM Planning Alternatives that will be evaluated are very plant-specific. Typical plant operating strategies and standard approaches to LCM Planning Alternatives are presented and discussed below.

- **Plant Strategy 1:** Operate the plant for its currently licensed period of 40 years.

  This strategy requires minimizing risk during the remaining operating period until the plant's license expires, and identifying limiting SSCs, which could result in premature power reduction or replacements forcing an economic decision regarding early decommissioning. LCM plan alternatives that might be developed under this strategy include:

  LCM Plan Alternative 1A: A base case to determine the cost of the activities performed under the current maintenance plan and assuming that the activities will continue as-is until the end of the licensed plant life. This case assumes also the ***continuation of the existing maintenance program*** without any major capital investments unless these are absolutely necessary.

  LCM Plan Alternative 1B: An alternative plan in which the current maintenance plan is optimized and ***an aggressive PM program*** is implemented to reduce equipment failures, lost power production and regulatory risk. The plan includes the purchase of an adequate breaker and breaker refurbishment kit inventory commensurate with the anticipated breaker failure rates, to achieve a 40-year lifetime. Without an obsolescence replacement program for the breakers, this alternative is judged to be limited to a 40-year operating strategy.

LCM Plan Alternative 1C: An alternative in which the current maintenance plan is optimized and ***obsolete breakers are fully or partially replaced*** with more reliable equipment and newer technologies. Variations to this alternative are schemes utilizing:

- Replacing only the safety-related and important-to-power-production breakers and returning the removed breakers to the warehouse after overhaul, to serve as spares for the remaining non-safety-related breakers.
- Instead of replacing only the breakers, the whole bucket or enclosure is rebuilt off-site with new equipment, ready to be installed in place of the old unit. This requires that the new cubicle mimics the physical dimensions and electrical characteristics of the original one. Reuse and refurbishment of the old equipment (to be used in non-safety service) could be a further variation of this scheme. The advantages of this alternative are reduced system downtime and complete upgrading (in contrast to only replacing the breaker with the remaining components, such as relays, trip units, transformers to be at a later time).

- **Plant Strategy 2:** Operate the plant for 60 years under a License Renewal Program

This strategy recognizes the potential for license renewal and extended operation of the plant. Major investments will be required to achieve extended operation. These investments can only be justified by the additional revenue generated in the additional 20-year operating term. LCM planning alternatives that might be considered under this strategy include:

LCM Plan Alternative 2A: This Alternative consists of a rigorous preparation for license renewal with an aggressive aging and obsolescence management program. Full or partial breaker or cubicle replacement should be considered, or as a minimum, inventory must be established to replace existing breakers until full breaker replacement is scheduled. Timely breaker replacements with new and improved models prior to starting the extended operating period should be contemplated. Depending on the current age of the plant, a second replacement with new technologies (such as solid state breakers and trip units) maybe required.

LCM Plan Alternative 2B: In this plan, the breakers are replaced in three stages, first, the safety-related breakers, then the non-safety but important to power production (critical) breakers and lastly the remaining ones. Replacement of the third group could be avoided, if the group 1 and 2 breakers are refurbished and stocked for future use in the non-critical applications.

7.2 Development of the Detailed Alternative LCM Plans

For each alternative LCM plan proposed, detailed maintenance activities and schedules need to be identified. Each plan will involve some mix of the LCM approaches in steps 13 to17 in Figure 2-1b. The plans might entail:

- Adjusting the frequency of time-directed maintenance activities to enhance the reliability of the breakers or reduce maintenance costs. The basis for such adjustments would be the trending of breaker failures and the failure causes.
- Considering additional diagnostics (PdM) such as thermography, acoustic monitoring and equipment condition feedback to convert time-directed to condition-directed maintenance.
- Combining the breaker PM with the overhaul at a ten-year frequency and reducing the PM to minimum non-invasive activities at 5-year intervals (greasing, exercising, visual inspection). This may reduce human error failures.
- Reviewing and updating the PM and overhaul procedures at least every 5 years to assure currency of addressing IOE and in-plant experience.
- Maintaining an adequate inventory of potentially obsolete breakers and their overhaul kits to assure that spares are available throughout the remaining period of operation or until the breakers are changed out with new models or upgraded technology.
- When contemplating breaker replacement, there are a number of options to be considered, each having its own cost and schedule impact:
  - Replacement with an identical breaker, if available. This is typically the lowest cost option, provided the new breaker is not excessively old (i.e. 20 years in the warehouse without exercising, greasing and overhaul). The vulnerable parts are the non-metallic components such as rubber, seals, gaskets, plastics, grease, lubricants, etc. If the new breaker is more than 10 years old (since leaving the factory), it should be refurbished or overhauled and tested prior to installation.
  - Replacement with an almost identical breaker (same electrical characteristics) but which has dimensional differences. The model can be from the same or a different vendor. This requires a form-fit-and-function assessment and may lead to alteration of the breaker cubicle, mounting plates, rails, panel doors and cutouts, stab contacts and internal cubicle wiring. Note that many replacement breakers are physically smaller and are positioned closer to the front panel door, which can lead to wiring problems. Care must be exercised not to void or impact the listing (NRTL) of the circuit breaker while these changes are made. If the breaker mass is substantially different or at a different location, seismic qualification of the panel/cubicle may be challenged.
  - Replacement with a new model or an upgraded technology. While this may be a preferred option for dealing with obsolescence, the drawback is the impact on the mechanical and electrical design provisions. New or different electrical characteristics (ampere and voltage rating, trip curves) may require in-depth engineering reviews, changes in diagrams and schematics, mechanical modification of the cubicle, development of new PM and testing procedures, training of maintenance crafts, adjusting the warehouse inventory for the old breakers and purchasing spares for the new breakers.

- Because breakers are an industry-wide obsolescence problem, other obsolescence contingencies that may be considered include formulation of agreements between a number of affected utilities with the same breaker models to share inventory, support continued manufacture of the breaker model and overhaul services by a vendor, or sponsorship and commitment for purchase of an acceptable replacement model breaker which includes all the interface engineering and qualification.

One alternative that will almost always be considered, if only as a base case for comparison to the other alternatives, is the option of continuing operation of the LVDS with the present breakers. This case will usually be based on the presumption that existing maintenance programs will continue and that present failure rates will apply or increase as the plant ages. However, in characterizing this base case, the obsolescence (and need for replacement or continued overhauls) of the breakers and the increase in failure rates as they reach the end of their life need to be carefully and realistically taken into account.

In characterizing each alternative task for LCM planning purposes, all costs and benefits should be considered. The data required for this purpose are reviewed in Sections 8 and 9.

7.3 Hypothetical Illustration of Assembling LCM Planning Alternatives

To illustrate the process of creating LCM Planning Alternatives, a hypothetical case was developed for the LVDS and the breakers. Assume that the plant is more than 20 years old (rated at 750 MW) and has breakers and MCCBs of various manufactures and models that dominate the failures and lost power generation and have contributed about 31000 lost MW Hours per year (0.47% to the plant UCLF). The 0.47% LPG represents about 10% of the total plant UCLF of 5% and is therefore 3-times the industry average of 3.5% (Table 4-2). As the breakers age, the failure rate and associated LPG is expected to increase, perhaps by as much as 10% per year, doubling each 10 years.

The review of the current maintenance practices noted that thermography is not performed and that the non-safety breakers are essentially run-to-failure components. The breakers are grouped by vendor and function, as well as by their association with the preventive maintenance programs. The safety and non-safety buses could be evaluated together due their similarity in PM.

The base case assumes that the plant is purchasing sufficient spare breakers and overhaul kits to be able to continue operation for the 40-year operating period. It is noted that this base case scenario would not be feasible for a 60-year operating strategy, unless a warehouse breaker PM and overhaul program is instituted to maintain the spare breakers for the long-term.

The LCM Alternative plan to the Base Case (continue the current maintenance plan) is to replace the 30-year old breakers as they become obsolete and as new solid state technology emerges. The timing of the replacements stretches out to the 2008 to 2014 time frame, to facilitate introduction of the new breakers in stages and to learn from the experience of the first stage. The activity details (Maintenance Activity Parameters, MAP’s) are as shown on Table 7-1 and include tasks for the replacement engineering and hardware modifications (of the cubicles). The cost of the new breakers, including rebuilding/replacing the other components and parts in the bucket, installation and testing, is assumed to be $40,000 per safety-related breaker. The LCM Alternative plan assumptions also include a reduction in the failure rates (to 0.005) for the new breakers and associated reduction of the LPG, which may offset the one-time high investment cost for the solid state breakers. Additionally, thermography is introduced for the breakers as well as a new PM frequency (71/2 years). System Engineer Walkdown and TS Surveillance tests are assumed to require half the effort for the new breakers.

For the non-safety breakers, replacements are only contemplated when the breaker fails. The replacement program for the safety breakers will yield sufficient spares to accommodate this option. To reduce the failure rate, a limited PM program is implemented, consisting of thermography for the critical breakers (about 50% are important to power production) and testing/exercising/lubricating the breakers on a regular basis. A failure rate and LPG reduction by a factor of 4 (from 0.072 to 0.018) is achievable to approach the industry average.

The difference in lost power generation between the base case and the Alternative is about 1.1 Million Dollars per year and the savings in maintenance cost for the Alternative is about 0.4 Million per year, for a total of about 1.5 Million. The breaker replacement with solid state technology will require an investment of about 19 Million Dollars over a period of 6 to 7 years. The calculated payback period is then about 12.5 years. As can be seen, the assumptions on failure rates and associated lost power generation are the principal cost components in the LCM planning for breakers and therefore the decision drivers. These assumptions therefore need to be well documented, benchmarked and must have a sound plant-specific basis.

When performing the actual analyses, using the NPV method, it is important to model the timing decisions for replacements correctly and to let the original activities continue in time until the replacement is implemented. Benefits (failure and LPG reductions and alternative PM activities) are realized only after replacements have been made.

The EPRI LCM planning tools (LcmPLATO or LcmVALUE) can be employed to determine the Alternative costs on a Net Present Value (NPV) basis. The tools are capable of handling fairly complex models, including non-linear failure assumptions and phasing in and out of individual tasks over time.

It should be stressed that the data used in the above example are hypothetical and are intended for demonstration purpose only.

The following are clarifications and abbreviations of data and terms used in the table:

- PM or CM denotes the type of activity (Preventive or Corrective)
- P or U denotes whether the activity is planned or unplanned
- N the number of components includes the total number to which the PM or CM is applied
- The actual labor hours should include any labor burden or task assistance such as fire watch, HP surveys, scaffolding, staging of tools, decontamination, WO writing, task briefing, etc.
- The actual labor costs are fully burdened and include benefits and any overhead multipliers.

- Material costs are inclusive of spare parts, overhaul kits, special tools, contract cost, replacements, consumables, etc.
- The frequency refers to the annual frequency of the planned activity or the failure rate (per year per component) of components for unplanned replacements.
- The total activity cost is simply the product of the other columns.

The values and number of components given in the table reflect a typical plant and may be used as guidance for grouping breakers and other LVDS components in a convenient way. Failure rates shown on the table are consistent with generic failure rates cited elsewhere in this report.

In reviewing this activity table, one can easily spot the largest annual expenditures and the impact a reduction or increase in PM frequency can have on the annual maintenance budget. The table also provides the data required as input to the EPRI LCM Planning Tools, LcmPLATO [37] or LcmVALUE [38].

Table 7-1
Sample Maintenance Activity Matrix for LVDS

ITEM	*ACTIVITY DESCRIPTION*	P, M, or, CM	P, or U	No. Of Comp. N	Actual Labor Hrs	Actual Labor Cost$/Hr	Material Cost$$	Actual Freq. or Failure RateFr	Total Activity CostBase Case$$	Total Activity Cost Alt. Case $$
1.0	Safety Rel. MCC Buckets, GE 7700-8000									
1.1	5-year PM, Electrician/Technician	P	P	449	24	45.50	120	0.2	108838	
1.2	Addit.10-year Overhaul Tasks	P	P	449	32	45.50	750	0.1	98388	
1.3	Replace Aux. Contacts	P	P	150	8	45.50	250	0.05	4605	
1.4	Grease Aux. Contacts (150 Size1)	P	P	150	8	45.50	0	0.1	9210	
1.5	Test and Trouble Shoot	P	P	449	18	45.50	150	0.4	174032	
1.6	Replace Bucket	C	U	449	30	45.50	25000	0.0035	41433	
1.7	Replace MCCB	C	U	449	18	45.50	1550	0.05	53154	
1.8	SE Walkdown	P	P	449	0.1	52	0	12	28018	14010
1.9	TS Surveillance Test	P	P	449	2.0	45.50	0	4	163436	81718
1.10	Lost Power Production	C	U	449			64000	0.017	488512	
2.0	Safety Rel. West., 5-Star MCC Buckets									
2.1	71/2-year PM, Technician/Electrician	P	P	26	36	45.50	120	0.133	6079	6079

ITEM	ACTIVITY DESCRIPTION	P, M, or, CM	P, or U	No. Of Comp. N	Actual Labor Hrs	Actual Labor Cost$/Hr	Material Cost$$	Actual Freq. or Failure RateFr	Total Activity CostBase Case$$	Total Activity Cost Alt. Case $$
2.2	Overhaul with Kit-Contract	P	P	26	Inc.		14000	0.083	30212	
2.3	Test and Trouble Shoot	P	P	26	20	45.50	150	0.4	11024	
2.4	Replace W5Star MCC Bucket	C	U	26	36	45.50	25000	0.0035	2424	
2.5	TS Surveillance Test	P	P	26	2.0	45.50	0	4	9464	9464
2.6	Lost Power Production	C	U	26			64000	0.017	28288	
3.0	Safety Rel. ABB K-Line Bus Breakers									
3.1	3-year PM	P	P	96	16	45.50	120	0.333	27109	
3.2	10-year Overhaul-Contract	P	P	96	Incl.		14000	0.1	134400	
3.3	Replace Failed Bus Breakers	C	U	96	8	45.50	2000	0.05	11347	
3.4	TS Surveillance Test	P	P	96	2	45.50	0	4	34944	17472
3.5	Lost Power Generation	C	U	96			64000	0.017	104448	
4.0	Non-Safety MCC Buckets									
4.1	Replace Failed Breakers or Fix	C	U	1404	24	45.50	300	0.072	140715	33224
4.2	10-year PM (50% Important Breakers)	P	P	702	24	45.50	75	0.10	81923	81923
4.3	Lost Power Generation	C	U	*351			64000	0.035	786240	
5.0	Non-Safety Bus Breakers									

ITEM	*ACTIVITY DESCRIPTION*	P, M, or, CM	P, or U	No. Of Comp. N	Actual Labor Hrs	Actual Labor Cost$/Hr	Material Cost$$	Actual Freq. or Failure RateFr	Total Activity CostBase Case$$	Total Activity Cost Alt. Case $$
5.1	6-year Breaker PM	P	P	111	16	45.50	100	0.167	15349	15349
5.2	Replace Failed Bus Breakers	C	U	111	8	45.50	300	0.033	2454	2454
5.3	Lost Power Generation	C	U	111			64000	0.017	120768	
6.0	RPS Trip Breakers (W-DB-50)									
6.1	Refueling PM	P	P	14	40	45.50	75	0.667	17696	5799
6.2	Test and Trouble Shoot	P	P	14	29	45.50	150	0.125	2572	
6.3	SP-TS Test	P	P	14	4	45.50	0	6.00	15288	7644
6.4	Replace RPS Breaker	C	U	14	8	45.50	46000	0.0588	38167	
6.5	Complete Overhaul, 10Y	P	P	14	60	45.50	750	0.10	4872	
7.0	Safety-related and Non-Safety Buses									
7.1	6-year Bus PM	P	P	24	16	45.50	200	0.167	3719	3719
7.2	Trip/Relay Testing	P	P	24	4	45.50	0	0.20	874	874
7.3	Trouble Shoot Bus	C	U	24	4	45.50	150	0.20	1594	1594
7.4	Bus Thermography	P	P	24	1	52	0	0.333	416	416
	New/Revised Activities for Alternative B1									

ITEM	*ACTIVITY DESCRIPTION*	P, M, or, CM	P, or U	No. Of Comp. N	Actual Labor Hrs	Actual Labor Cost$/Hr	Material Cost$$	Actual Freq. or Failure RateFr	Total Activity CostBase Case$$	Total Activity Cost Alt. Case $$
1.11	Replace Bucket with Solid State	R	P	449			30000	2008-11		3367500
1.12	Thermography on Energized Breakers	P	P	449	1	52		0.5		11674
1.13	Change to 7 ½ year PM	P	P	449	8	47.75	50	0.133		93039
1.14	Interface Engineering	P	P	1			50000	In 2008		50000
1.15	Hardware Modifications	P	P	449	12	45.50	100	2008-11		72514
1.16	Lost Power Generation	C	P	449			64000	0.005		>2010
1.17	Replace Solid State Breakers	C	U	449	16	45.50	30000	0.005		>2010
2.7	Replace W5S with Solid State	R	P	26			40000	2012-13		520000
2.8	Thermography on Energized Breakers	P	P	26	1	52		0.5		676
2.9	Interface Engineering	P	P	1			15000	In 2011		15000
2.10	Hardware Modifications	P	P	26	12	45.50	100	2012-13		8398
2.11	Lost Power Generation	C	U	26			64000	0.005		8320
2.12	Replace Failed Solid State Breakers	C	U	26	16	45.50	40000	0.005		5295

ITEM	*ACTIVITY DESCRIPTION*	P, M, or, CM	P, or U	No. Of Comp. N	Actual Labor Hrs	Actual Labor Cost$/Hr	Material Cost$$	Actual Freq. or Failure RateFr	Total Activity CostBase Case$$	Total Activity Cost Alt. Case $$
3.4	Replace Bus Breakers with Solid State	R	P	96			40000	2014-16		960000
3.5	Thermography on Bus Breakers	P	P	96	1	52		0.5		2496
3.6	Change to 71/2-year PM	P	P	96	16	45.50	0	0.133		9318
3.7	Lost Power Generation	C	U	96			64000	0.005		30720
3.8	Replace Failed Solid State Breakers	C	U	96	16	45.50	40000	0.005		19550
3.9	Interface Engineering	P	P	1			20000	In 2013		20000
3.10	Hardware Modifications	P	P	96	12	45.50	100	2014-16		20672
4.3	Thermography on Critical Breakers	P	P	702	0.5	52	0	0.5		9126
4.4	Test and Exercise Critical Breakers, 50%	P	P	702	1	45.50	0	0.333		10636
4.5	Lost Power Generation	C	U	351			64000	0.01		224640
5.4	Thermography on Bus Breakers	P	P	111	0.5	52	0	0.5		1443
5.5	10-year Overhaul-Contract	P	P	111	Inc		10000	0.1		111000
5.6	Lost Power Generation	C	U	111			64000	0.01		71040

ITEM	*ACTIVITY DESCRIPTION*	**P, M, or, CM**	**P, or U**	**No. Of Comp. N**	**Actual Labor Hrs**	**Actual Labor Cost$/Hr**	**Material Cost$$**	**Actual Freq. or Failure RateFr**	**Total Activity CostBase Case$$**	**Total Activity Cost Alt. Case $$**
6.6	Thermography	P	P	14	1	52	0	0.667		485
6.7	Change to 3-year PM	P	P	14	12	45.50	150	0.333		3245
6.8	Replace Breakers with Solid State	P	P	14			40000	2011-13		186480

The blue field indicates that the base case activity is discontinued or replaced for the case B1

8
GUIDANCE FOR ESTIMATING FUTURE FAILURE RATES

This section addresses a part of step number 18 of Figure 2-1b. Failure rates are a main driver of the LCM planning process.

General guidance for estimating SSC future failure rates can be found in Section 2.6 of the LCM sourcebook overview report [3]. Below are some ideas useful for estimating failure rates in LVDS LCM planning studies.

- Table 6-1 provides the estimated "Useful Life of Breakers." These data may be used to estimate the expected remaining life of the LVDS breakers and other components and parts. If "in-kind" replacements are made, existing failure rates may be applied for the future.
- Plants that have a breaker performance trending program can extract breaker failure data and compute failure rates for the various types and sizes of breakers. Data can be plotted as a function of time to determine if aging effects are playing a role or if the current PM programs are effective.
- Corrective Work Orders (WOs) provide a means of reconstructing the breaker failures and to compute failure rates. Caution is in order when reviewing WOs, because some plants consider breaker overhaul as corrective maintenance, while other plants may not issue WOs for replacement of non-safety breakers. The WO review should encompass the last 5 years of data to generate meaningful results.
- Failure rate reductions can be achieved by installing redundant or spare components (breakers) or entire buses. If the LCM plan considers such design changes, future failure rate projections must consider the effect of redundancy, as discussed in the LCM sourcebook overview report [3].
- Many of the non-safety-related breakers serve system functions, such that a single failure rarely causes a loss of the entire system function or the loss of the system function does not cause a trip. While the component failure (and its repair or replacements) must be considered in the LCM planning, it may not be an incident of lost power generation.
- Most of the safety-related breakers are associated with the safety-related systems (ECCS, ESF, etc) that have redundant trains. A breaker failure causing a loss of one train of a safety system will not trigger an immediate trip or scram, but will require entry into an LCO (Limited Condition of Operation) condition. Various time limits are established based on the individual safety system risk, ranging from a few hours to 7 days. If the breaker cannot be fixed or replaced and returned to operational status within that time limit, plant shutdown must be initiated.

- Some breakers are serving the reactor protection system and a single breaker failure can place the plant into a "Half Scram" position. Any additional failure will cause an immediate plant trip (scram), or if the redundant channel already was in the half scram position a plant trip would occur. RPS breakers therefore require special attention to achieve a very low failure rate.
- When deciding to overhaul or refurbish breakers by outside contractors, the historic plant-specific failure rate may no longer apply. Experience with refurbished breakers shows an increase in failure rates due to human errors associated with refurbishment.
- When breakers are replaced with a similar model from a different vendor, the failure rates may be different. A reasonable projection is to use the existing failure rate, until a new failure rate can be determined (based on failure trending), unless the vendor has reliable failure data to support a different rate.
- If plant-specific breaker failure rates are not readily available from plant databases, the plant-specific PRA may be a source of reliability values for use in LCM planning. The following identify some useful ideas and cautions in the use of PRA data.
  - For the base case, these PRA based failure rates may be used in projecting future failure rates.
  - The PRA based failure rates for breakers are likely expressed in demand failures (or reliability). These values can be converted to failure rates, if the annual demands (actual and tests) are known. Some breakers have cycle counters from which the demands can be read.
  - When the plant-specific PRA is used as a basis for the plant-specific system failure rates, verification of the basis for the PRA input should be considered. It is also important to assure that the PRA reflects the actual plant LVDS configuration, including the non-safety portion of the LVDS.
  - Maintenance Rule programs and PRAs emphasize functional failures rather than degraded performance. Many breakers fail in a fail safe position (the odds are 50-50), where no system function was lost.

In summary, failure rate predictions for plant-specific LVDS components and breakers are made using the above LVDS-specific guidance and the generic guidance presented in Section 2.6 of the LCM sourcebook overview report. PRA and Maintenance Rule records may be an important source of information. If plant-specific failure rates for breakers are not available, one of the top priorities in LCM planning should be to implement a comprehensive breaker performance trending program. The LCM planning process should be fairly complete with carefully defined specific activities for each of the LCM alternative plans. In this way, the influence of new or additional PM activities, implementation of replacements, and redesigns can be appropriately considered in estimating future failure rates for input to LCM economic evaluations.

9
PLANT-SPECIFIC GUIDANCE FOR ECONOMIC MODELING

This section addresses the cost prediction part of step number 19 in the LCM planning flowchart (Figure 2-1b).

In this LVDS LCM sourcebook, generic cost information is presented based on recent EPIX data, as discussed in Section 4.1. For critical breakers (those that, if they fail, can cause a plant trip or scram) the average lost power generation cost was established as $64,000 per event assuming unplanned power replacement cost at $50.00 per MWH.

No other generic cost data are presented since such data will be of little use to individual plants, given the significant variations in equipment types and sizes, plant-specific accounting practices and maintenance programs. The cost data given in Table 7-1, while typical and fairly representative, is purely hypothetical.

When developing LCM plans for the LVDS and the breakers, equipment items (e.g., breaker types and vendor models, buses) can be best addressed in sets of component commodity groups, preferably separated into safety and non-safety-related commodity groups to accommodate the differences in maintenance activities. This approach will generally be more efficient, provided the commodity or breaker groups comprise SSCs of similar type and manufacture, as routine maintenance will be identical and the failure history of the SSCs within the group will be relevant and applicable.

When developing Alternatives, it is best to formulate plans that are relatively simple and do not include massive changes all at once. A step-wise approach will provide simplicity and retain overview of the plan. For instance, a first step from the base case would be the conversion to a more effective preventive maintenance program for the breakers, including breaker failure trending, thermography, exercising and lubrication with a new grease. The additional costs and savings can then be determined for the remaining life of the plant and the impact on breaker failure reduction can be illustrated. The next step could be to add a phased replacement of one breaker group and their reuse in non-safety service. This step could include consideration of lost power generation, the failure rates for the new breakers and the reduction in LPG. Subsequent steps can then add other features and variations to get a feeling for the decision drivers.

Section 3.8 of the Overview Report [3] contains a generic discussion and listing of the typical financial data to be collected and specified as input to the economic evaluations of alternative LCM plans.

10
INFORMATION SOURCES AND REFERENCES

10.1 Information Sources

The references provided below were found to be the most relevant origins of meaningful data. While most of the useful information from these sources has already been mined and summarized in this sourcebook, individual plants nevertheless may find it useful to interrogate plant-specific data sorts or search for equipment failures under the same vendor, model or size.

1. Institute of Nuclear Power Operations, INPO Website, SEE-IN provides up-to-date information and listings of industry-wide component problems documented in:

   a. Operating Experience Reports (OEs)

   b. Operations and Maintenance Reminders (O&MRs)

   c. Significant Event Reports (SERs)

   d. Significant Event Notifications (SENs)

   e. Significant Operating Experience Reports (SOERs)

2. Institute of Nuclear Power Operations, NPRDS and EPIX Databases provide equipment failure reports and sorts by equipment code, system code, vendor, failure mode, plant, etc.

3. EPRI Generic Communications Database, Version 3.0, Release 4.0, October 2001, provides applicable generic communications sorts (for safety-related SSCs only) by equipment name, type of NRC document, aging mechanisms, aging effects for the following NRC documents:

   a. Generic Letters (GL)

   b. Information Bulletins (IB)

   c. Information Notices (IN)

   d. Regulatory Issue Summaries (RIS)

   e. Generic Safety Issues (GSI)

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