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Equipment Failure Model and Data for Distribution-Voltage-Class Protection Equipment

A PM Basis Application

1010886

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Technical Update, December 2005

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Asset Performance Technologies, Inc.

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

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This document describes research sponsored by EPRI.

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

Equipment Failure Model and Data for Distribution-Voltage-Class Protection Equipment: A PM Basis Application, EPRI, Palo Alto, CA: 2005. 1010886

PRODUCT DESCRIPTION

Increasing pressure from both customers and regulators to maintain and enhance service reliability, while at the same time controlling costs, has put many utilities' distribution businesses in a classic dilemma of conflicting objectives. For that reason, asset management has become an increasingly important aspect of corporate business strategies. A significant focus of EPRI's asset management research in recent years has been to develop a rational basis for selecting repair or replacement options for specific classes of equipment by balancing the risks of equipment failure against the costs of continued maintenance or capital replacement.

Results & Findings

With billions of dollars of utility power delivery infrastructure now nearing the end of its useful life, determining when to replace these assets is critical to the financial health of many utilities. EPRI has developed a decision framework that enable utilities to generate business cases for these investments, which takes a life-cycle costing approach that enables corporate financial managers and regulators to assess the multi-year financial impacts of maintaining specific classes of power delivery infrastructure assets. One of the key drivers in these asset management decisions are the projected failure rates of the assets as they age.

The primary purpose of this report is to provide data on equipment failure mechanisms and preventive maintenance that can be used systematically to estimate failure rates of the following distribution-voltage-class (DVC) protection components: circuit breakers (air gap, vacuum bottle, and oil-filled), reclosers (oil-filled, oil-filled vacuum bottle, SF_6-filled vacuum bottle, and solid dielectric), fused disconnect, and lightning arrestors (silicon carbide and MOV).

Challenges & Objectives

Estimating equipment failures is a critical challenge to applying EPRI's asset management tools. Ideally, a utility's maintenance records would provide sufficient data to estimate them. However, in many cases, for a variety of reasons they are not. Ultimately, too, working collaboratively through EPRI, industry-wide equipment testing and failure analysis databases could be assembled to provide these estimates. However, given the scale and time that will be required to develop these databases, it is necessary to find some ways to provide failure information for asset management purposes in the interim. This report develops an alternative approach to estimating equipment failure rates by describing an equipment failure model based on a combination of expert judgment and available data.

Applications, Values & Use

This report provides baseline data on failure causes and for the calculation of failure rates of DVC protection components. In addition, it also provides a model for utilities to adapt those estimates to the particular service conditions that exist in their systems. These estimates can drive asset management decisions regarding the inventory of these components, including decisions on testing and maintenance intervals. Users of this information will be asset managers and analysts in development of economical strategies for maintenance of DVC protection components.

This document also discusses common preventive maintenance (PM) tasks used by utilities to identify and mitigate the causes and mechanisms that lead to the degradation and failure of these types of component. They can be used in conjunction with information and recommendations from other sources to develop a PM program or to improve an existing program. Users of this information will be utility managers, supervisors, craft technicians, and training instructors responsible for developing, optimizing, or fine-tuning PM programs.

EPRI Perspective

Information gathered for this report on DVC protection components has also been loaded into the EPRI PM Basis Database (EPRI 1010919), which was developed for EPRI's Nuclear Power Division. The broad objective of the PM Basis project is to develop a preventative maintenance basis for a large number of component types in utility power systems (including nuclear and fossil generating plants, transmission and distribution systems) using information supplied by the industry. This report extends the content of the PM Basis by incorporating information for an important category of power delivery equipment.

Furthermore, this report uses the PM Basis to develop equipment failure models for DVC protection components, which defines how these types of components deteriorate over time and quantifies the rates at which deterioration occurs. The model thus permits projecting failure rates for each component type as a function of the various service conditions and stressors that may be present. One result of these calculations would be to establish failure rate data for use in asset management decision models. Other uses of the models include establishing condition and failure codes for use in data collection and tracking, and calibrating failure rates through use of such data.

Approach

The process used to develop a PM Basis for a component follows a well defined sequence of steps. The process utilizes a combination of the information developed by a panel of experts and further information derived from analysis performed using computerized algorithms resident in the EPRI PM Basis Database. Major process steps include: establishing the boundary of the equipment to be considered, identifying major subcategories, establishing the functional importance, service conditions, and duty cycles that influence equipment degradation, establishing failure locations, determining degradation processes, the factors that influence them, and their time characteristics, listing degradation discovery opportunities and their effectiveness, describing PM tasks and their effectiveness.

Keywords

Distribution
Distribution Lightning Arrestor
Distribution Circuit Breaker
Preventive Maintenance
Distribution Recloser
Maintenance Optimization
Distribution Fused Disconnect
Component Reliability

ACKNOWLEDGEMENTS

This report resulted from an Expert Workshop on Maintenance for Selected Distribution-Voltage-Class Protection Components, held on October 18-19, 2005 at the Kansas City Power and Light offices in Kansas City, MO. These experts took time from their very busy schedules to provide the information on which this report is based. We appreciate their contributions. The expert panel was composed of the following individuals:

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1
INTRODUCTION

1.1 Background

The current state of the electric power industry has placed unprecedented strains on the assets used to deliver power to energy customers. Increasing pressure from both customers and regulators to maintain and enhance service reliability, while at the same time controlling costs, has put many distribution companies in a classic dilemma of conflicting objectives. Faced with this situation, companies are scrutinizing investment and maintenance expenditures much more rigorously than in the past. For that reason, asset management has become an increasingly important aspect of corporate business strategies.

A significant focus of EPRI's asset management research in recent years has been to develop a rational basis for selecting repair or replacement options for specific equipment by balancing the risks of equipment failure against the costs of continued maintenance or capital replacement. EPRI has developed several products (EPRI 1000422, 1001703, 1001704, 1001872, 1001873, 1002086, 1002092) that enable utilities to generate business cases for investments, evaluate risks, and focus scarce manpower and investment resources on high-value solutions. The decision framework embodied in these products takes a life-cycle costing approach that enables corporate financial managers and regulators to assess the multi-year financial impacts of maintaining specific classes of power delivery infrastructure assets.

In general, equipment failures accelerate as they age, and at some point, the costs of outages, repairs, and emergency replacements exceed the costs of planned replacements. With billions of dollars of utility power delivery infrastructure now nearing the end of its useful life, determining when to replace these assets is critical to the financial health of many utilities. Thus, some of the key drivers in these asset management decisions are the projected failure rates of the assets as they age.

Estimating equipment failures is a critical challenge to applying these decision tools. Ideally, a utility's maintenance records would provide sufficient data to estimate them. However, in many cases, for a variety of reasons they are not. Ultimately, too, working collaboratively through EPRI, industry-wide equipment testing and failure analysis databases could be assembled to provide these estimates. However, given the scale and time that will be required to develop these databases, it is necessary to find some ways to provide failure information for asset management purposes in the interim. This report develops an alternative approach to estimating equipment failure rates by describing a method for modeling equipment failures based on a combination of expert judgment and available data.

1.2 Objective

The primary purpose of this report is to provide data on equipment failure mechanisms and preventive maintenance that can be used systematically to estimate failure rates of the following distribution-voltage-class (DVC) protection components: circuit breakers (air gap, vacuum bottle, and oil-filled), reclosers (oil-filled, oil-filled vacuum bottle, SF_6-filled vacuum bottle, and solid dielectric), fused disconnect, and lightning arrestors (silicon carbide and MOV).

In addition to baseline data, the report also provides an equipment failure model that enables utilities to adapt those estimates to the particular service conditions that exist in their systems. The intended use of these estimates is to drive asset management decisions regarding component inventory, including decisions on testing and maintenance intervals and on component replacement policies. Users of this information will be asset managers and analysts in the development of economical strategies for distribution class component management.

The technical approach used in this report, called *PM Basis*, which is described in the next section, also facilitates the development of preventative maintenance programs; indeed, that is the purpose for which it was developed. The broad objective of the PM Basis project is to develop a preventative maintenance basis for a large number of component types in utility power systems (including nuclear and fossil generating plants, transmission and distribution systems) using information supplied by the industry. Thus, an important secondary use of this document is to provide a program of preventive maintenance (PM) tasks suitable for application to selected distribution class components. The PM tasks that are identified represent common practices used by utilities to identify and mitigate the causes and mechanisms that lead to component degradation and failure. They can be used in conjunction with information and recommendations from other sources to develop a PM program or to improve an existing program. However, they should not be considered recommended practices; each utility must evaluate the cost effectiveness of these practices in light of their own circumstances. Users of this information will be utility managers, supervisors, craft technicians, and training instructors responsible for developing, optimizing, or fine-tuning PM programs.

Information gathered for this report on the following DVC protection components: circuit breakers (air gap, vacuum bottle, and oil-filled), reclosers (oil-filled, oil-filled vacuum bottle, SF_6-filled vacuum bottle, and solid dielectric), fused disconnect, and lightning arrestors (silicon carbide and MOV) has also been loaded into the EPRI PM Basis Database (EPRI 1010919), which was developed for EPRI's Nuclear Power Division. The tables presented in the remainder of this report represent a combination of the information developed by the expert panel and further information derived from analysis performed using computerized algorithms resident in the EPRI PM Basis Database.

1.3 Technical Approach

The process used to develop a PM Basis for a component follows a well defined sequence of steps. The process utilizes a combination of the information developed by the expert panel and further information derived from analysis performed using computerized algorithms resident in the EPRI PM Basis Database. The expert panel for the distribution class components contained in this report was composed of the individuals cited in the acknowledgements section of this report. The process facilitates the expert group reaching agreement on the details of the PM template and its supporting basis information. Major process steps are:

1) Review maintenance and failure cause data obtained from relevant industry documents to categorize failure types and to gauge the relative effectiveness of current maintenance practices.
2) Subdivide the component type into logical groups by design characteristics. The following 10 DVC protection components were selected to be added to the database, as listed below.

Table 1-1 Distribution-Voltage-Class Protection Component Types

- Distribution Circuit Breaker - Air Gap - 1kV to 34kV
- Distribution Circuit Breaker - Vacuum - 1kV to 34kV
- Distribution Circuit Breaker - Oil-filled - 1kV to 34kV
- Distribution Recloser - Oil-filled
- Distribution Recloser - Oil-filled - Vacuum Bottle
- Distribution Recloser - SF_6-filled - Vacuum Bottle
- Distribution Recloser - Solid Dielectric
- Distribution Disconnect - Fused
- Distribution Lightning Arrestor - Silicon Carbide
- Distribution Lightning Arrestor - MOV

3) Define the boundary of each component type for the purpose of the database. The boundary divides the component itself from equipment that is attached to it, and it basically represents the components that would ordinarily be included in an inspection and maintenance program.

   For example: The boundary of an Oil-filled Distribution Recloser is the Recloser itself, and including: Tank or tanks, oil, operating mechanism, aux switches, bushings, interrupters; support components, if present, such as battery, battery charger, capacitor-trip, heaters, thermostat, fuses, wiring, controller; and the primary leads.

4) Establish the functional importance, service conditions, and duty cycles that influence degradation and impact PM strategies for these component types.

   In general, duty cycle captures stressors on the equipment that result from intensity of use. Think, for example of a pump, for which a high duty cycle would indicate continuous use and low duty cycle would indicate occasional use. In general, service condition captures stressors on the equipment that result from the operating environment.

5) Establish a preliminary PM task list (that is, inspections and tests) to assist in defining how failure causes can be discovered.

6) Divide the component into major maintainable subgroups.

7) Establish failure locations. Failure locations are the places on a component where degradation can occur.

8) Determine degradation processes, the factors that influence the degradation, and the time characteristics of the progression to failure.

   Degradation processes represent the various ways in which a component deteriorates over time. Degradation Mechanisms and Influences that may be experienced at each Failure Location are presented in adjacent columns of the failure model tables presented in chapter 3 (denoted 3.X.3). Each failure location may have one or more degradation mechanisms acting upon it, and each degradation mechanism may have more than one influence affecting it. Each degradation influence may determine a different timing characteristic of a particular mechanism. In general, degradation mechanisms are assumed to proceed independently of one another.

   The influence factors may also include particular stressors that, if they are present to an uncommon degree, can accelerate the progression of degradation by a particular mechanism. For instance, in the Air Gap type of Circuit Breaker, temperature influences the two degradation mechanisms, 1) the deterioration of insulation, and 2) the hardening of lubricant, so that if the circuit breaker is operated in an unusually hot environment these degradation mechanisms will proceed more quickly than the time code (described below) indicates.

   The time code column in the of the failure model tables presented in chapter 3 represents the rate at which deterioration occurs by the particular mechanism under the influence shown in the preceding failure location, degradation mechanism, and degradation influence columns. It can be thought of as the expected time until the earliest failures of the equipment occur due to that mechanism. The time codes are discussed in section 2.3.1.

At this point in the process, one has defined an *equipment failure model* for one of the DVC protection component types. That is, such a model defines how the individual component type deteriorates over time, and quantifies the rates at which deterioration occurs. The model thus permits projecting failure rates for the component as a function of the various service conditions and stressors that may be present. One result of these calculations would be to establish failure rate data for use in the asset management models discussed above. Other uses of the models include establishing condition and failure codes for use in data collection and tracking, and calibrating failure rates through use of such data. Of course, a primary use of the model is to establish a preventative maintenance basis for the equipment. The remaining steps of the process address that function.

9) List the discovery opportunities for each of the subcomponent failure locations. Discovery opportunities mean inspections and tests that can be applied to determine the extent of deterioration. As is well known, most of the inspections and tests that can be applied do not unambiguously indicate the extent of deterioration, the true extent of which may be unobservable. For instance, the presence of air leaks in air compressor tubing and fittings on Oil-filled Circuit Breaker may not be fully discoverable by visual inspection alone. Therefore, the effectiveness of each test was also rated by the expert panel.

10) List the final PM strategies and tasks considered by the expert panel to be effective in discovering degradation and preventing the onset of the failure mechanism, or in returning the component to an as new condition through accepted preventive maintenance techniques. These PMs for these components are considered to be common practices in the industry but should not be considered recommended practices; each utility must evaluate the cost effectiveness of these practices in light of their own circumstances.

11) List the effectiveness (high, medium, low) of each PM task for addressing each degradation mechanism using high or H equal to 97%, medium or M equal to 80%, and low or L equal to no more than 50/50 chance of detecting a problem should it exist at the time the task is performed.

12) Describe the objective and scope of each PM task.

13) Develop a maintenance template providing PM tasks and task intervals which summarize the information developed in the previous items.

14) Develop a list of recent and relevant industry references.

The recommended Template task intervals are moderately conservative values intended to be default values for the case when a utility has no basis for its existing task intervals. They are based on a synthesis of current utility experience and may not be suitable for direct application by a given utility without careful consideration of its own service history. It is essential for utilities to continue to adjust intervals based on their own service experience. The information most likely to be useful to assist in this process would be information on as-found equipment condition.

1.4 Contents

This first chapter explains the approach used to develop the equipment failure model for components discussed in this report using the PM Basis Database methodology and the strategic considerations that influenced the expert working group.

Chapter 2 provides an explanation of the format in which the data gathered from the expert working group is presented in detail later in Chapter 3. The data is provided in tabular form and structured into logical groupings that together represent useful information to the maintenance professional on where and how these components degrade over time, what preventive maintenance tasks are seen as effective, and when those tasks might be performed. For each of the 10 component types discussed in this report, the data along with the results obtained by utilizing the PM Basis Database tools is presented in three convenient tables: Definitions, PM Template, and the component's Degradation Data Table.

Chapter 3 contains the details and results of the data gathering and analysis processes for each of the components listed in Table 1-1.

2 EXPLANATION OF FAILURE MODELS

This chapter provides an explanation of the contents of the failure models developed in the expert workshop and presented in detail later in Chapter 3. The data is provided in tabular form and structured into logical groupings that together represent useful information to the maintenance professional on where and how these components degrade over time, what preventive maintenance tasks are seen as effective, and when those tasks might be performed.

For each of the 10 component types discussed in this report, the data along with the results obtained by utilizing the PM Basis Database tools is presented in three convenient tables: Definitions, PM Template, and the component's Degradation Data Table. The process was necessarily fairly repetitive to ensure that each set of circumstances (i.e. component failure location and degradation mechanism) was given proper consideration.

Using the process described in chapter 1 and summarized herein, the expert group developed for each component the following information:

1) *Definitions* describing the component's boundary and the reasons for performing maintenance - its functional importance (herein called criticality), duty cycle and service conditions.

2) *PM Template and Task Description* listing the preventive maintenance tasks the group felt to be effective, when they might be performed, and the supportive information detailing the basis for each task.

3) *Component Degradation Data* table describing where and how these components degrade over time.

2.1 Definitions: Boundary Definition, Functional Importance, Duty Cycle, and Service Condition

The boundary definition provides a simple description of what the expert group felt was included within the scope of the preventive maintenance program they recommended for each of the component types in this report. The boundary definition serves to divide the component itself from equipment that is attached to it, and it basically represents the components that would ordinarily be included in an inspection and maintenance program.

The reason for and the extent of the preventive maintenance performed on a given component can be explained by the functional importance it has, and the service conditions and duty cycles it experiences that influence its rate of degradation. All three of these are used to establish the PM strategies which might effectively be applied to these component types described in this report.

Functional importance or criticality defines whether or not the equipment is considered important enough from a production or financial stand point to require a comprehensive or a minimal maintenance program in order to maintain that equipment's ability to function reliably. The fullest extent of the recommended maintenance program would therefore be brought to bear on equipment judged to be critical, while equipment of lesser functional importance would receive a smaller, less expensive PM program.

Duty cycle captures stressors on the equipment that result from intensity of use. For example think of a pump for which a high duty cycle would indicate continuous use and a low duty cycle would indicate occasional use. In general, service conditions capture stressors on the equipment that result from the operating environment.

2.2 PM Template and Task Description

The PM Template is a tabulation of the preventive maintenance program in a concise format. The PM tasks that are identified represent common practices used by utilities as identified by the expert panel. However, they should not be considered recommended practices. Each utility must evaluate the cost effectiveness of these practices in light of their own circumstances. The 'Template' tabulates the recommended tasks and task intervals for a range of functional importance, duty cycle, and service conditions.

The template consists of eight columns. Each column represents one of the eight possible combinations (often called 'categories') of functional criticality (**C**ritical or **M**inor), duty cycle (**H**igh or **L**ow), and service condition (**S**evere or **M**ild).

For each PM task, a task interval (how a task interval is derived and should be applied is described later) is usually provided for each of the eight possible combinations. The intervals represent the suggested best time a particular task should be performed when the component is best described by one of the eight template categories described earlier. The intervals usually consist of a number and a single letter indicating the time in months or years, e.g. 3M = 3 months, 2Y = 2 years, and so forth. Two additional interval representations are 'NA' defined as 'Not Applicable' (i.e. no PM task recommended for this template category), and 'AR' defined as 'As Required' (i.e. the expert group could not recommend a specific best interval or felt the task was to be performed as an on-condition task).

Each PM Template has associated information describing how the template information is to be applied and ways in which it may be modified by the user to more closely represent their particular asset of needs and conditions. These notes were the same for each of the 10 component types and are provided at the end of this section in *PM Templates Notes and Definitions*.

A Task Description is provided for each PM task following each PM Template. The Task Description consists of a Task Objective – why the task is performed, the task's PM Basis – what and how well the degradation mechanisms are addressed by the task, as well as an outline of suggested Task Content – which activities go with each level of inspection.

The PM basis is derived by using the *EPRI PM Basis Database's* tools and provides information on: *Failure Locations and Causes* – what degradations mechanisms and influences are addressed by the task, *Progression of Degradation to Failure* – how the degradation mechanism progress in time from initiation to where they can no longer be tolerated, and *Fault Discovery and Intervention* – how effective the task is at discovering the degradation condition, assuming the degradation condition exists at the time the task is performed.

2.2.1 Determination and Use of Task Intervals

The general PM task intervals suggested in this report should be determined and adjusted by each utility based on individual experience and vendor recommendations. Intervals provided in the template are suggested starting points for this process, although in general, where these tasks are already being performed, the existing intervals could be used as the starting point providing a basis exists for them. Such a basis could be constructed from condition assessment data, past inspection data and failure history, and from information in this document. A key point is that it is prudent to change time-directed intervals in the search for intervals that are short enough to protect against unacceptable equipment deterioration, but not so short as to waste maintenance resources or to introduce unnecessary sources of maintenance error.

When selecting time intervals for intrusive PM tasks, it is not necessarily conservative to select shorter rather than longer time intervals in a possible range. Shorter intervals expose the equipment to more opportunities for maintenance error and to the potential for maintenance-induced damage.

2.2.2 PM Template Notes and Definitions

This subsection contains three areas: Template Definitions, General Precautions, and Use of Vendor Recommendations.

Template Definitions

PM task interval designations used:

- AR - As Required
- NA – Not Applicable
- NR – Not Recommended
- Y – Years
- M – Months

General Precautions:

Note, this program assumes that the component of interest is considered to be nominally good condition. Components that have not been serviced for a long time may need to have an inspection performed and remedial action taken before the outlined program is to be applied.

The Expert Panel felt there was sufficient cause to perform tasks with intervals as close as possible to the intervals indicated in the template unless specific means are employed to add confidence that a more extended interval can be used (e.g. visual inspection, maintenance history, as-found conditions).

Deferral of any task requires an evaluation. One evaluation method would be to compare, using a sampling process, the candidate component's maintenance history and as-found conditions to those of other components with similar specifications and operating conditions.

If the component operates in severe service conditions, the specific conditions must be considered in order to select appropriate intervals.

If there are specific conditions (i.e. one or more columns) for which no PM task is appropriate, this is considered to be Run-To-Failure (RTF). RTF is only a maintenance option for those non-critical components that meet all the following conditions:

- The component is not required for vital system redundancy,
- The component's failure does not promote failure of other components,
- It is more cost-effective to repair or replace the component after failure than to do preventive maintenance,
- There is no simple cost-effective task to maintain the component.

Existing regulatory requirements should always be followed. If the above recommendations differ from these regulations the more conservative approach should be followed.

Use of Vendor Recommendations

The information and recommendations contained in this report should be used in conjunction with recommendations provided by the original component vendor.

The basis for departures from vendor recommendations needs to be carefully considered and documented. The information in this report should enable decisions involving departures from those recommendations to be made with a greater awareness of the specific failure causes that are involved, and the indications of degradation that can show whether or not the decision was appropriate as time passes. It is recognized that a specific PM task may address many failure causes that are also addressed by other tasks. This may provide for overlapping between tasks that can make such decisions less critical by the adoption of compensating actions.

2.3 Component Degradation Data Table

The data gathered for each of the component types is presented as a tabular summary of the equipment failure models, including degradation and failure mechanism information obtained by direct interviews with the expert panel members in a joint workshop format. The data obtained represents the panel's opinions of the factors that influence failure: 1) where failures are most likely to occur, 2) the degradation mechanisms, 3) the factors that influence the degradation, 4) how the degradation progresses over time, 5) the opportunities to recognize the onset or status of the degradation, and 6) the PM actions and strategies that can be employed to discover or prevent the failure from occurring, and the effectiveness of these activities.

The component degradation data table identifies the many failure locations which, in their maintenance experience, the expert group knows to have occurred. The group went on to identify the leading degradation mechanisms, the main physical influences on the degradation, and the time progression of the degradation for each failure location. For each case (i.e. failure location, degradation mechanism, and degradation influence – the first 3 columns in each table), the expert group considered the time scale when the degradation would actually become a failure (coding this information is described below). This information is presented in the first four columns of each component's degradation data table.

The next columns in the table describes how effectively specific PM tasks, e.g. infrared and other diagnostic testing, can detect a significantly degraded condition (these tasks are described in the section detailing the PM Template and Task Descriptions). Task effectiveness for the purpose of the *EPRI PM Basis Database* is defined as high, medium, or low. Each task is rated on how well it is seen as addressing each degradation mechanism using high or H equal to 97% chance of success in preventing the degraded condition from becoming an in-service failure, medium or M equal to 80%, and low or L equal to no more than a 50% chance of detecting a problem should it exist at the time the task is performed.

The tables of detailed information presented here can also support utilities wanting to modify the suggested tasks or task intervals to account for their specific conditions.

2.3.1 Coding Time-To-Failure

The time code column in each component degradation data table represents the rate at which deterioration occurs by the particular mechanism under the particular influence shown in the preceding columns. It can be thought of as the expected time until the earliest failures of the equipment occur due to that mechanism. "W" time codes show the time in years that a wear-out mechanism typically takes to lead to the earliest failures – an analogue of minimum life. A range of years indicates uncertainty in this minimum life.

When the W is not accompanied by a “U”, it means the wear-out mechanism is not experienced by every component, but must be triggered by the existence of a special condition, or by another event, taken to be a random occurrence. In contrast, a “UW” code indicates a wear-out mechanism that is universally experienced and that starts to degrade the component as soon as it is put into service. An R in the time code indicates a randomly occurring degradation mechanism. Normally, the random mechanisms individually do not exert a strong influence on the failure rate, but their random occurrence pattern makes them hard to avert unless PM tasks are performed very frequently.

3
COMPONENT DATA: DEFINITIONS, PM TEMPLATES, AND DEGRADATION TABLES

This chapter presents the preventive maintenance program for the following DVC protection components: **circuit breakers** (air gap, vacuum bottle, and oil-filled), **reclosers** (oil-filled, oil-filled vacuum bottle, SF_6-filled vacuum bottle, and solid dielectric), **fused disconnects**, and **lightning arrestors** (silicon carbide and MOV). Each of the component types can be found in its own chapter section, numbered 3.1 to 3.10. The major component sections are then divided into three subsections (3.X.1, 3.X.2, and 3.X.3) which present the information and analysis for each component type. The data found in each subsection is a follows:

3.X.1 – Definitions

- Boundary Definition, Functional Importance, Duty Cycle, and Service Condition

3.X.2 – PM Template and Task Description

- PM Template and Intervals
- Individual Tasks with Objective, Failure Locations and Causes, Progression of Degradation to Failure, Fault Discovery and Intervention, Task Content.

3.X.3 – Component Degradation Data Table and PM Strategies

- Failure Location, Degradation Mechanism, Degradation Influence, Time Code, and PM Task Effectiveness.

3.1 Distribution Circuit Breaker - Air Gap - 1kV to 34kV

3.1.1 *Definitions: Boundary, Criticality, Duty Cycle, and Service Condition*

Boundary Definition

The Air Gap Distribution Circuit Breaker itself, including the switchgear enclosure, circuit breaker, and their accessories, as follows:

Indoor switchgear enclosure including racking mechanism, busbar and insulation, cabinets, interlocks and switches, source side bus PTs (potential transformer) and bus CTs (current transformer), load CTs, and control wiring.

Circuit breaker including racking mechanism (if attached to the circuit breaker), truck, operating mechanism, main current components, arc chutes or arc quenching devices, and auxiliary switches and contacts.

Electrical devices such as control wiring, switches (e.g. auxiliary switches, control relay, trip coils), indicators, and local metering.

Protective relays, such as undervoltage, overcurrent, ground fault, and field monitor, are excluded.

Functional Importance

Critical

Functionally important, e.g., required for critical lines, e.g. feeding hospitals or large customers. These would normally be primary feeders.

Minor

Functionally not important, but economically important, e.g. for any of the following reasons: high frequency of resulting corrective maintenance, more expensive to replace or repair than to do preventive maintenance, has a high potential to cause the failure of other critical or economically important equipment. These would normally be lateral lines. If the failure is not functionally important and also not economically important this would correspond to Run-To-Failure, but these cases are excluded from the Template.

Duty Cycle

High

Circuit Breakers experiencing 10 or more operations or cycles per year

Low

Circuit Breakers experiencing less than10 operations or cycles per year

Service Condition

Severe

Despite the indoor location: High or excessive humidity, excessive temperatures (high or low) or temperature variations, excessive environmental conditions (e.g. salt, prone to flooding, corrosive, spray), high vibration.

Mild

Clean indoor area, temperatures within OEM specifications, normal environmental conditions.

3.1.2 PM Template and Task Description

		Critical Functional Importance				Minor Functional Importance			
	Duty Cycle:	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
	Service Condition:	**Severe**	**Severe**	**Mild**	**Mild**	**Severe**	**Severe**	**Mild**	**Mild**
Circuit Breaker Maintenance	See PM Application Note 3.1.2.1	5Y	4Y	5Y	4Y	8Y	6Y	8Y	6Y
Substation Inspection	See PM Application Note 3.1.2.2	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Breaker Operation - Open and Close Breaker	See PM Application Note 3.1.2.3	2Y	1Y	2Y	1Y	4Y	2Y	4Y	2Y

3.1.2.1 Circuit Breaker Maintenance

Task Objective:

This task has the objective of making sure that the breaker will function as required, mainly by addressing lubrication and wear-out issues. The interval is not tightly constrained by the underlying failure information.

Failure Locations and Causes:

The primary focus of Circuit Breaker Maintenance is to address the replenishing of lubricants in accessible locations, and the subsequent redistribution of lubricants to minimize the effects of hardening in all moving breaker components; and to detect wear, damage, and deterioration of the operating and breaker racking mechanism. Additionally, damage and wear of the main and auxiliary current carrying components may be detected before they progress to a failed condition, especially in locations with severe service conditions.

Progression of Degradation to Failure:

The lubrication-related causes contributing to a functional loss of the circuit breaker may appear in as little as 6 years in severe service conditions, especially when there is little to no opportunity to redistribute the lubricant, i.e. when there are long periods of breaker inactivity.

Fault Discovery and Intervention:

The interval is not tightly constrained, and supports the task interval being in the range of 4 to 6 years.

The Scope of Circuit Breaker Maintenance is as Follows:

- Verify the integrity of breaker frame grounds and anchoring
- Manually operate the breaker – "feel" for binding (experience needed)
- Perform as-found electrical test (open/close and timing)
- Clean and replace lubricant where accessible and not requiring further disassembly i.e. contact stabs, easily accessible pivot points, and primary contacts (if required)
- Refresh the lubricant at bearing and pivot points where it is impossible to replace it
- General cleaning and inspection of all accessible parts and surfaces
- Verify adjustments
- Inspect puffer and verify operation
- Perform contact resistance test
- Perform insulation resistance test
- Perform a power factor test
- Inspect for: missing, loose, or damaged parts, fasteners, and set screws; tracking on insulators; cracked welds; rust or corrosion; cracked or burned arc chutes; secondary control block damage or misalignment; worn or bent linkages; general cleanliness; condition of prop springs; wiring harness damage.
- Perform as-left electrical test (open/close and timing)

3.1.2.2 Substation Inspection

Task Objective:

This task verifies proper operation of indicating lamps and other indicators, and the general appearance of the breaker. The task interval is not constrained by the underlying failure information.

Failure Locations and Causes:

Substation Inspection's principle value is in evaluating the general condition of the circuit breakers and their surroundings, specifically assuring that the breaker's position indicators are working, and that the breakers are in the correct operating position.

Progression of Degradation to Failure:

These degradation mechanisms are fairly long-term wear-out mechanisms.

Fault Discovery and Intervention:

The underlying failure information does not suggest that this task need be performed more often than every few years. The annual performance is therefore more likely due to service personnel being in the substation for other reasons.

The Scope of Substation Inspection is as Follows:

- Verify breaker status - that the individual breaker is in the correct open/closed position and that the operating handle is in the proper operating position
- Verify proper operation of indicating lamps
- Record 3 phase load reading
- Visually inspect for presence of moisture and condensation
- Note general conditions, e.g. covers, doors
- Reset targets
- Record operation counter readings

3.1.2.3 Breaker Operation - Open and Close Breaker

Task Objective:

This task serves to exercise the breaker's moving parts, to prove the operability, and to redistribute the lubricants. The task interval may not be well supported, because scheduling of outages may be a problem.

Failure Locations and Causes:

The primary focus of Breaker Operation is to address the redistribution of lubricants thus minimizing the effects of hardening from lack of use in all moving breaker components, e.g. operating and racking mechanisms, and to discover loose, worn, damaged, or misaligned electrical devices, such as breaker stabs, microswitches and secondary disconnects.

Progression of Degradation to Failure:

The lubrication-related causes contributing to a functional loss of the circuit breaker may appear in as little as 6 to 10 years in severe service conditions, especially with little to no opportunity to redistribute the lubricant associated with long periods of breaker inactivity.

Fault Discovery and Intervention:

The interval is not tightly constrained, but it is probably a good idea to operate the breaker every 2 or 3 years at a minimum in order to redistribute the lubricant.

The Scope of Breaker Operation - Open and Close Breaker is as Follows:

- This task should be performed with the breaker in-place
- Perform all activities of the Substation Inspection for the breaker
- Electrically operate (remote operation is suggested) the breaker taking note of abnormal noise and general operation
- Perform and record breaker open/close timing test, be sure to capture the first operation (where possible - not always feasible)

3.1.3 *Failure Locations, Degradation Mechanisms, and PM Strategies*

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Circuit Breaker Maintenance	Substation Inspection	Breaker Operation Open and Close Breaker
Bus Stabs (Breaker)	Misalignment	Installation error	R	H		
Electrical Devices (micro switches, aux. switches, secondary disconnects, local control handle, fuse blocks, aux. relays, charging motor, heaters)	High contact resistance	Contamination, especially with inactivity	W10	H	L	M
Electrical Devices (micro switches, aux. switches, secondary disconnects, local control handle, fuse blocks, aux. relays, charging motor, heaters)	Insulation breakdown	Age, Temperature	UW40	M		M
Electrical Devices (micro switches, aux. switches, secondary disconnects, local control handle, fuse blocks, aux. relays, charging motor, heaters)	Insulation breakdown	Current-time overload	R	M		M

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Circuit Breaker Maintenance	Substation Inspection	Breaker Operation Open and Close Breaker
Electrical Devices (micro switches, aux. switches, secondary disconnects, local control handle, fuse blocks, aux. relays, charging motor, heaters)	Loose and Worn	Age, especially microswitches and secondary disconnects	UW20	H	L	M
Electrical Devices (micro switches, aux. switches, secondary disconnects, local control handle, fuse blocks, aux. relays, charging motor, heaters)	Loose, Worn, Damaged, Misaligned	Personnel error and vibration	R	H	L	M
Lubricant	Hardened, Loss of lubricity	Age, especially with inactivity	UW6_10	M		M
Lubricant	Hardened, Loss of lubricity	Temperature, contamination	W6_10	M		M
Main Current, Arc Quench, and Insulation	Arcing, tracking, or corona	Contamination	R	H		
Main Current, Arc Quench, and Insulation	Arcing, tracking, or corona	Insulation breakdown, moisture absorption	R	H		
Main Current, Arc Quench, and Insulation	Damaged or Failed parts	Personnel error and vibration	R	H		
Main Current, Arc Quench, and Insulation	Damaged Plating, Pitted, or Corroded Contacts	Contamination	W10	H		
Main Current, Arc Quench, and Insulation	Damaged Plating, Pitted, or Corroded Contacts	Fault current interruption	R	H		

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Circuit Breaker Maintenance	Substation Inspection	Breaker Operation Open and Close Breaker
Main Current, Arc Quench, and Insulation	Damaged Plating, Pitted, or Corroded Contacts	Normal wear (age, cycles)	UW15_50	H		
Main Current, Arc Quench, and Insulation	Insulation failure of main current and phase insulation components	Contamination, moisture	W10	M		
Main Current, Arc Quench, and Insulation	Insulation failure of main current and phase insulation components	Temperature	W10	M		
Operating Mechanism	Damaged, Worn, Loose or Failed parts	Normal wear	UW10_20	H		L
Operating Mechanism	Damaged, Worn, Loose or Failed parts	Personnel error	R	H		L
Operating Mechanism	Damaged, Worn, Loose or Failed parts	Vibration	W6	H		L
Racking Mechanism and Shutter Assembly	Damaged, worn, loose or failed parts	Normal wear	UW10_20	M		
Racking Mechanism and Shutter Assembly	Damaged, worn, loose or failed parts	Personnel error, abuse	R	M		

3.2 Distribution Circuit Breaker - Vacuum - 1kV to 34kV

3.2.1 *Definitions: Boundary, Criticality, Duty Cycle, and Service Condition*

Boundary Definition

The Vacuum Bottle Distribution Circuit Breaker itself, including the switchgear enclosure, circuit breaker, and their accessories, as follows:

Indoor switchgear enclosure including racking mechanism, busbar and insulation, cabinets, interlocks and switches, source side bus PTs (potential transformer) and bus CTs (current transformer), load CTs, and control wiring.

Circuit breaker including racking mechanism (if attached to the circuit breaker), truck, operating mechanism, main current components, arc chutes or arc quenching devices including vacuum bottles, and auxiliary switches and contacts.

Electrical devices such as control wiring, switches (e.g. auxiliary switches, control relay, trip coils), indicators, and local metering.

Protective relays, such as undervoltage, overcurrent, ground fault, and field monitor, are excluded.

Functional Importance

Critical

Functionally important, e.g., required for critical lines, e.g. feeding hospitals or large customers. These would normally be primary feeders.

Minor

Functionally not important, but economically important, e.g. for any of the following reasons: high frequency of resulting corrective maintenance, more expensive to replace or repair than to do preventive maintenance, has a high potential to cause the failure of other critical or economically important equipment. These would normally be lateral lines. If the failure is not functionally important and also not economically important this would correspond to Run-To-Failure, but these cases are excluded from the Template.

Duty Cycle

High

Circuit Breakers experiencing 10 or more operations or cycles per year

Low

Circuit Breakers experiencing less than 10 operations or cycles per year.

Service Condition

Severe

Despite the indoor location: High or excessive humidity, excessive temperatures (high or low) or temperature variations, excessive environmental conditions (e.g. salt, prone to flooding, corrosive, spray), high vibration.

Mild

Clean indoor area, temperatures within OEM specifications, normal environmental conditions.

3.2.2 *PM Template and Task Description*

		Critical Functional Importance				Minor Functional Importance			
	Duty Cycle:	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
	Service Condition:	**Severe**	**Severe**	**Mild**	**Mild**	**Severe**	**Severe**	**Mild**	**Mild**
Circuit Breaker Maintenance	See PM Application Note 3.2.2.1	5Y	4Y	5Y	4Y	8Y	6Y	8Y	6Y
Substation Inspection	See PM Application Note 3.2.2.2	1Y	1Y	1Y	1Y	1Y	1Y	1Y	1Y
Breaker Operation - Open and Close Breaker	See PM Application Note 3.2.2.3	2Y	1Y	2Y	1Y	4Y	2Y	4Y	2Y

3.2.2.1 Circuit Breaker Maintenance

Task Objective:

This task has the objective of making sure that the breaker will function as required, mainly by addressing lubrication and wear-out issues. The interval is constrained by the underlying failure information, leaving little opportunity for extension.

Failure Locations and Causes:

The primary focus of Circuit Breaker Maintenance is to address the replenishing of lubricants in accessible locations, and the subsequent redistribution of lubricants to minimize the effects of hardening in all moving breaker components, and to detect wear, damage, and deterioration of the operating and breaker racking mechanism. Additionally, damage and wear of the main and auxiliary current carrying components may be detected before they progress to a failed condition, especially in locations with severe service conditions.

Progression of Degradation to Failure:

The lubrication-related causes contributing to a functional loss of the circuit breaker may appear in as little as 6 years in severe service conditions, especially with long periods of breaker inactivity.

Fault Discovery and Intervention:

The interval is rather well determined by the underlying failure information, leaving little opportunity for extension.

The Scope of Circuit Breaker Maintenance is as Follows:

- Verify the integrity of the breaker frame, grounds, and anchoring
- Manually operate the breaker – "feel" for binding (experience needed)
- Perform an as-found electrical test (open/close and timing)
- Clean and replace the lubricant where accessible and not requiring further disassembly i.e. contact stabs, easily accessible pivot points, and primary contacts (if required)
- Refresh the lubricant at bearing and pivot points, where it is impossible to replace it
- Perform a general cleaning and inspection of all accessible parts and surfaces
- Verify all adjustments
- Inspect the puffer and verify operation (not feasible-located inside vacuum bottle)
- Perform a Hi-pot test to verify condition of the vacuum bottle
- Perform a contact resistance test (may indicate loss of bottle vacuum)
- Perform an insulation resistance test
- Perform a power factor test
- Inspect for: missing, loose, or damaged parts, fasteners, and set screws; tracking on insulators; cracked welds; rust or corrosion; cracked or burned arc chutes; secondary control block damage or misalignment; worn or bent linkages; general cleanliness; condition of prop springs; and wiring harness damage.
- Perform an as-left electrical test (open/close and timing).

3.2.2.2 Substation Inspection

Task Objective:

This task verifies proper operation of indicating lamps and other indicators, and the general appearance of the breaker. The task interval is not constrained by the underlying failure information.

Failure Locations and Causes:

Substation Inspection's principle value is in evaluating the general condition of the circuit breakers and their surroundings, specifically assuring that the breaker's position indicators are working, and that the breakers are in the correct operating position.

Progression of Degradation to Failure:

These degradation mechanisms are fairly long-term wear-out mechanisms.

Fault Discovery and Intervention:

The underlying failure information does not suggest that this task need be performed more often than every few years. The annual performance is therefore more likely due to service personnel being in the substation for other reasons.

The Scope of Substation Inspection is as Follows:

- Verify breaker status - that the individual breaker is in the correct open/closed position and that the operating handle is in the proper operating position
- Verify proper operation of indicating lamps
- Record 3 phase load readings
- Visually inspect for presence of moisture and condensation
- Note general conditions, e.g. covers, doors
- Reset targets
- Record operation counter readings

3.2.2.3 Breaker Operation - Open and Close Breaker

Task Objective:

This task serves to exercise the breaker's moving parts, to prove the operability, and to redistribute the lubricants. The task interval may not be well supported, because scheduling of outages may be a problem.

Failure Locations and Causes:

The primary focus of Breaker Operation is to address the redistribution of lubricants thus minimizing the effects of hardening from lack of use in all moving breaker components, e.g. operating and racking mechanisms, and to discover loose, worn, damaged, or misaligned electrical devices, such as breaker stabs, microswitches and secondary disconnects.

Progression of Degradation to Failure:

The lubrication-related causes contributing to a functional loss of the circuit breaker may appear in as little as 6 to 10 years in severe service conditions, especially with little to no opportunity to redistribute the lubricant associated with long periods of breaker inactivity.

Fault Discovery and Intervention:

The interval is not tightly constrained, but it is probably a good idea to operate the breaker every 2 or 3 years at a minimum in order to redistribute the lubricant.

The Scope of Breaker Operation - Open and Close Breaker is as Follows:

- This task should be performed with the breaker in-place
- Perform all activities of the Substation Inspection for the breaker
- Electrically operate (remote operation is suggested) the breaker taking note of abnormal noise and general operation
- Perform and record breaker open/close timing test, be sure to capture the first operation (where possible - not always feasible)

3.2.3 *Failure Locations, Degradation Mechanisms, and PM Strategies*

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Circuit Breaker Maintenance	Substation Inspection	Breaker Operation Open and Close Breaker
Bus Stabs (Breaker)	Misalignment	Installation error	R	H		
Electrical Devices (micro switches, aux. switches, secondary disconnects, local control handle, fuse blocks, aux. relays, charging motor, heaters)	High contact resistance	Contamination, especially with inactivity	W10	H	L	M

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Circuit Breaker Maintenance	Substation Inspection	Breaker Operation Open and Close Breaker
Electrical Devices (micro switches, aux. switches, secondary disconnects, local control handle, fuse blocks, aux. relays, charging motor, heaters)	Insulation breakdown	Age, Temperature	UW40	M		M
Electrical Devices (micro switches, aux. switches, secondary disconnects, local control handle, fuse blocks, aux. relays, charging motor, heaters)	Insulation breakdown	Current-time overload	R	M		M
Electrical Devices (micro switches, aux. switches, secondary disconnects, local control handle, fuse blocks, aux. relays, charging motor, heaters)	Loose and Worn	Age, especially microswitches and secondary disconnects	UW20	H	L	M
Electrical Devices (micro switches, aux. switches, secondary disconnects, local control handle, fuse blocks, aux. relays, charging motor, heaters)	Loose, Worn, Damaged, Misaligned	Personnel error and vibration	R	H	L	M
Lubricant	Hardened, Loss of lubricity	Age, especially with inactivity	UW6_10	M		M

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Circuit Breaker Maintenance	Substation Inspection	Breaker Operation Open and Close Breaker
Lubricant	Hardened, Loss of lubricity	Temperature, contamination	W6_10	M		M
Main Current, Arc Quench, and Insulation	Arcing, tracking, or corona	Contamination	R	H		
Main Current, Arc Quench, and Insulation	Arcing, tracking, or corona	Insulation breakdown, moisture absorption	R	H		
Main Current, Arc Quench, and Insulation	Damaged or Failed parts	Personnel error and vibration	R	H		
Main Current, Arc Quench, and Insulation	Damaged Plating, Pitted, or Corroded Contacts	Contamination	W10	H		
Main Current, Arc Quench, and Insulation	Damaged Plating, Pitted, or Corroded Contacts	Fault current interruption	R	H		
Main Current, Arc Quench, and Insulation	Damaged Plating, Pitted, or Corroded Contacts	Normal wear (age, cycles)	UW15_50	H		
Main Current, Arc Quench, and Insulation	Insulation failure of main current and phase insulation components	Contamination, moisture	W10	M		
Main Current, Arc Quench, and Insulation	Insulation failure of main current and phase insulation components	Temperature	W10	M		

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Circuit Breaker Maintenance	Substation Inspection	Breaker Operation Open and Close Breaker
Operating Mechanism	Damaged, Worn, Loose or Failed parts	Normal wear	UW10_20	H		L
Operating Mechanism	Damaged, Worn, Loose or Failed parts	Personnel error	R	H		L
Operating Mechanism	Damaged, Worn, Loose or Failed parts	Vibration	W6	H		L
Racking Mechanism and Shutter Assembly	Damaged, worn, loose or failed parts	Normal wear	UW10_20	M		
Racking Mechanism and Shutter Assembly	Damaged, worn, loose or failed parts	Personnel error, abuse	R	M		

3.3 Distribution Circuit Breaker - Oil-filled - 1kV to 34kV

3.3.1 *Definitions: Boundary, Criticality, Duty Cycle, and Service Condition*

Boundary Definition

The Oil-filled Distribution Circuit Breaker itself, including the switchgear enclosure, circuit breaker, and their accessories, as follows:

Outdoor switchgear enclosure including racking mechanism, busbar and insulation, cabinets, interlocks and switches, source side bus PTs (potential transformer) and bus CTs (current transformer), load CTs, and control wiring.

Circuit breaker including racking mechanism (if attached to the circuit breaker), truck, operating mechanism, main current components, arc quenching devices, and auxiliary switches and contacts.

Electrical devices such as control wiring, switches (e.g. auxiliary switches, control relay, trip coils), indicators, and local metering.

Protective relays, such as undervoltage, overcurrent, ground fault, and field monitor, are excluded.

Functional Importance

Critical

Functionally important, e.g., required for critical lines, e.g. feeding hospitals or large customers. These would normally be primary feeders.

Minor

Functionally not important, but economically important, e.g. for any of the following reasons: high frequency of resulting corrective maintenance, more expensive to replace or repair than to do preventive maintenance, has a high potential to cause the failure of other critical or economically important equipment. These would normally be lateral lines. If the failure is not functionally important and also not economically important this would correspond to Run-To-Failure, but these cases are excluded from the Template.

Duty Cycle

High

Circuit Breakers experiencing 10 or more operations/cycles per year

Low

Circuit Breakers experiencing less than 10 operations/cycles per year.

Service Condition

Severe

Outdoor locations that experience: High or excessive humidity, excessive temperatures (high/low) or temperature variations, excessive environmental conditions (e.g. salt, prone to flooding, corrosive, spray), high vibration.

Mild

Despite the outdoor location: Absence of the above conditions.

3.3.2 *PM Template and Task Description*

		Critical Functional Importance				Minor Functional Importance			
	Duty Cycle:	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
	Service Condition:	**Severe**	**Severe**	**Mild**	**Mild**	**Severe**	**Severe**	**Mild**	**Mild**
Circuit Breaker Maintenance	See PM Application Note 3.3.2.1	5Y	4Y	5Y	4Y	8Y	6Y	8Y	6Y
Substation Inspection	See PM Application Note 3.3.2.2	1M	1M	1M	1M	1Y	1Y	1Y	1Y
Breaker Operation - Open and Close Breaker	See PM Application Note 3.3.2.3	2Y	1Y	2Y	1Y	4Y	2Y	4Y	2Y
Oil Analysis	See PM Application Note 3.3.2.4	2Y	1Y	2Y	1Y	4Y	2Y	4Y	2Y

3.3.2.1 Circuit Breaker Maintenance

Task Objective:

This task has the objective of making sure that the breaker will function as required, mainly by addressing compressor lubrication and breaker contamination issues. There is little to no room for external extension.

Failure Locations and Causes:

Circuit Breaker Maintenance addresses several conditions: the build-up of external contamination on the bushings; condition of the oil used for both its insulating and lubricating properties; problems with the air compressor system, especially plugging of the breather or filter, and dirty compressor oil. This task provides a general assessment of the overall condition of the breaker's wiring, actuation devices and linkages, the close and trip solenoids, and the compressed air system.

Progression of Degradation to Failure:

The majority of the degradation mechanisms addressed by this task occur in as little as 5 years to as short as ~2 years in severe service conditions. Additionally, the failure rate does not appear to be driven by duty cycle but by the service condition.

Fault Discovery and Intervention:

The interval of 4 years is not well supported for the highest duty cycles and most severe service conditions, due to the relatively short wear-out period, e.g. 2 to 3 years of the most likely failure mechanisms. Therefore, there does not appear to be an opportunity for interval expansion.

The Scope of Circuit Breaker Maintenance is as Follows:

- Verify the integrity of the breaker frame, grounds, and anchoring
- Include all tasks from the Substation Inspection.
- Remove and filter the oil.
- Clean, inspect, and repair the:
  - Tank and tank liners, where fitted
  - Interrupter (main and arcing contacts, resistors)
  - Bushings, including cleaning the outside surface
  - Dashpot
- Lubricate operating mechanism
- Lubricate trip and close latch
- Perform a slow close to check the alignment and contact wipe
- Replace the door gasket
- Re-filter and refill with the same oil
- Touch up the paint around the door
- Perform a power factor and timing test
- Change the air compressor oil, if present.
- Check the tightness of all connections.
- Perform a Functional test which includes diagnostics of the "Capture the first trip" type.

3.3.2.2 Substation Inspection

Task Objective:

This task addresses water logging of the air receiver tank and the general appearance of the breaker. The interval provides some room for extension, but not beyond 1 year depending on the environmental conditions the breaker experiences.

Failure Locations and Causes:

Substation Inspection for these outdoor distribution voltage circuit breakers addresses the general condition of all the components exposed to service conditions stressors, e.g. salt spray, dirt, and weather. The primary degradation mechanism covered by this task is water logging of the air receiver tank, as well as a wide range of other degradation mechanisms.

Progression of Degradation to Failure:

Water logging of the air receiver tank can occur in 6 months to a year, especially in humid conditions. Compressor problems as well as build-up of contamination of the surface of bushings can occur over a relatively few years.

Fault Discovery and Intervention:

The interval provides some room for extension, but not beyond 1 year depending on the environmental conditions the breaker may experience. No other task has an interval short enough to address the receiver tank water logging and plugging of the air compressor breather. Therefore any interval extension should be made very carefully.

The Scope of Substation Inspection is as Follows:

- Verify the integrity of the breaker frame grounds and anchoring
- Breaker status check, verifying that the individual breaker is in the correct open/closed position and that the operating handle is in the proper operating position
- Verify proper operation of indicating lamps
- Record 3 phase load reading
- Visually inspect for the presence of moisture and condensation
- Note general conditions, e.g. covers, doors
- Reset targets
- Verify that the cabinet heater and thermostat are operable
- Record operation counter readings
- Drain water from the air compressor receiver
- Inspect compressor for signs of abnormal wear, e.g. belts and sheaves
- Verify oil level in bushing sight glass, if present
- Verify oil level in tank
- Inspect bushings for damage and cleanliness
- Inspect for air leaks - check compressor run hour meter, if present, to verify compressor is not running too frequently

3.3.2.3 Breaker Operation - Open and Close Breaker

Task Objective:

This task serves to exercise the breaker's moving parts, to prove the operability, and to redistribute the lubricants. The task interval may not be well supported, because scheduling of outages may be a problem.

Failure Locations and Causes:

This task primarily addresses binding of the open/trip solenoid linkages from lack of use. Additionally, a visual examination of the breaker's externals is possible during the performance of the task.

Progression of Degradation to Failure:

The degradation mechanisms addressed by this task are mostly wear-outs and range in time from a few to many years.

Fault Discovery and Intervention:

The task interval is appropriate for heavily contaminated environments, leaving room for the exploration of reasonable interval extension for nominal service conditions.

The Scope of Breaker Operation - Open and Close Breaker is as Follows:

- Perform all activities of the Substation Inspection for the breaker
- Electrically operate (remote operation is suggested) the breaker taking note of abnormal noises and general operation
- Perform and record breaker open/close timing test, be sure to capture the first operation

3.3.2.4 Oil Analysis

Task Objective:

This task verifies the condition of the oil. The task interval is not well supported, leaving room for the exploration of reasonable interval extension.

Failure Locations and Causes:

Oil Analysis primarily focuses on the condition of the insulating oil and its loss of dielectric strength from contact and operating mechanism wear products created during breaker operations, as well as the condition and cleanliness of the oil, especially from water ingress, which can promote tank contamination and disbondment of the tank's liner, if present.

Progression of Degradation to Failure:

The degradations mechanisms addressed by this task are mostly wear-outs and range in time of a few to several years.

Fault Discovery and Intervention:

The task interval is not well supported, leaving room for the exploration of reasonable interval extension.

The Scope of Oil Analysis is as Follows:

- Oil quality (color, acidity), moisture, and particulates.
- Dielectric test
- Power factor test
- DGA is normally performed only as an on-condition task when a problem has been found, and is not a regularly scheduled activity

3.3.3 *Failure Locations, Degradation Mechanisms, and PM Strategies*

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Circuit Breaker Maintenance	Substation Inspection	Breaker Operation Open and Close Breaker	Oil Analysis
Aux/AB Switch	High resistance connections	Contamination, moisture	R	L		L	
Aux/AB Switch	Out of adjustment	Duty cycle, normal wear	R	H		L	
Cabinet heater	Open	Aging	UW40	H	H		
Close and Trip Coils	Open coil	Aging	R	H	H	H	
Close and Trip Solenoids	Bound linkages	Dirt, contamination, lack of use, failed lubricant	W5	H		H	
Close and Trip Solenoids	Bound plunger	Dirt, contamination	R	H		H	
Dash pots	Bad seals	Normal wear	UW40	H			
Door Gasket	Leakage	Aging	UW20	H	H		
Door Gasket	Leakage	Improper assembly	R	H	H		
Fuse	Blown	Aging, overload	R	H			

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Circuit Breaker Maintenance	Substation Inspection	Breaker Operation Open and Close Breaker	Oil Analysis
Fuse	Loose / corroded holders	Contamination, heat	R	H	M		
Grading Resistors	Open	Fault, normal wear	R	H			
Hydraulic Mechanism - Accumulator	Improper precharge pressure	Personnel error	R	H			
Hydraulic Mechanism - Accumulator	Ruptured bladder	Aging	UW10_15	H	M		
Hydraulic Mechanism - Check Valve	Seat leakage	Normal wear	UW10	M	L		
Hydraulic Mechanism - Motor	Failed	Normal wear, overheating	UW40	H	H	H	
Hydraulic Mechanism - Pump	Failed	Normal wear	UW40	H	H	H	
Hydraulic Mechanism - Tubing, Fittings, gauges	Leaks	Normal wear, vibration	R	H	H	M	
Interrupter	Erosion of arcing and main contacts	Fault current interruptions	W5_8	H			M
Interrupter	Erosion of arcing contacts	Normal wear	UW8_12	H			M
Interrupter	Main and Arcing Contact Coking	Gas in oil from contact overheating	R	H			

Interrupter	Misaligned contacts	Personnel error	R	H			M

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Circuit Breaker Maintenance	Substation Inspection	Breaker Operation Open and Close Breaker	Oil Analysis
Interrupter	Misaligned contacts	Worn linkages	UW40	H			M
Lift Rod and Guides	Cracked or broken	Contact misalignment	R	H			
Lift Rod and Guides	Warped	Water	R	H			
Linkage	Out of adjustment	Normal wear	R	H			
Linkage	Seized bearings	Lack of lubrication	W5_10	M		M	
Linkage	Worn bearings	Normal wear	UW40	M			
Oil	Contamination	Gassing from contact overheating	R				H
Oil	Contamination	Gassing from fault interruption	R				H
Oil	Loss of dielectric	Particulates (carbon, metal, fiber)	UW5	H	M		H
Oil	Loss of dielectric	Water	R	H			H
Oil	Low oil level	Leaks	R	H	H		H
Oil-filled Bushings	External contamination	Dirt, salt, environmental conditions	UW5	M	M	L	M
Oil-filled Bushings	Leakage	Chipped or cracked porcelain	R	M	L		M

Oil-filled Bushings	Leakage	Improper maintenance techniques	R	M	L		M
Oil-filled Bushings	Leakage	O-ring failure	UW15	M	L		M

Failure Location	**Degradation Mechanism**	**Degradation Influence**	**Time Code**	**Circuit Breaker Maintenance**	**Substation Inspection**	**Breaker Operation Open and Close Breaker**	**Oil Analysis**
Oil-filled Bushings	Leakage	Over-temperature from high internal resistance	R	M	L		M
Oil-filled Bushings	Loss of BIL	Chipped or cracked porcelain	R	M	L		
Oil-filled Bushings	Loss of BIL	Improper maintenance	R				
Oil-filled Bushings	Loss of BIL	Internal contamination	R				
Oil-filled Bushings	Loss of BIL	Low oil level	R	M	L		
Oil-filled Bushings	Loss of BIL	Manufacturing techniques	R				
Oil-filled Bushings	Loss of BIL	Operation above rating	R				
Oil-filled Bushings	Loss of BIL	Voltage surges (e.g. lightning strikes)	R				
Pneumatic Mechanism - Air Compressor	Contaminated oil	Dirt, wear particles, water	UW5	H	M		
Pneumatic Mechanism - Air Compressor	Overheating, excessive wear	Air leak	R	M	M		
Pneumatic Mechanism - Air Compressor	Plugged breather/filter	Dirt, water	UW5	H	L		
Pneumatic Mechanism - Air Compressor	Worn / Misaligned belt	Normal wear, loose mounting	W4_8	H	H		

Pneumatic Mechanism - Air Compressor	Worn or broken Reed valves	Normal wear, overheating	UW10	M	M			
Pneumatic Mechanism - Air Compressor	Worn sheaves	Normal wear, loose mounting	W4_8	H	H			

Failure Location	**Degradation Mechanism**	**Degradation Influence**	**Time Code**	**Circuit Breaker Maintenance**	**Substation Inspection**	**Breaker Operation Open and Close Breaker**	**Oil Analysis**
Pneumatic Mechanism - Alarms and Switches	Drift	Normal wear, dirty air lines	UW40				
Pneumatic Mechanism - Motor	Failed	Normal wear, overheating	UW20	H	H	H	
Pneumatic Mechanism - Receiver Tank	Water logged	Normal compressor operation (moisture from heat of compression)	UW1	H	H		
Pneumatic Mechanism - Tubing, Fittings, gauges	Leaks	Normal wear, vibration	R	M	L		
Tail Spring, shock absorber	Broken	Manufacturing defect	R	H			
Tail Spring, shock absorber	Out of adjustment	Loose jam nut	R	M			
Tail Spring, shock absorber	Weak	Normal wear	UW40	M			
Tank	Cracked weld, leak	Manufacturing defect	R	M			L
Tank	Internal contamination	Particulates (carbon, metal, fiber)	UW5	M			H
Tank	Internal contamination	Water ingress	R	M			H
Tank Liner	Disbondment	Water ingress	R	M			
Thermostat	Drift	Normal wear	R		L		
Thermostat	Inoperable	Aging	UW40	H	H		

Wiring	Degraded insulation	Animal damage	UW20	H	M		
Wiring	Loose connections	Heat	UW20	H			

3.4 Distribution Recloser - Oil-filled

3.4.1 *Definitions: Boundary, Criticality, Duty Cycle, and Service Condition*

Boundary Definition

Tank or tanks, oil, operating mechanism, aux switches, bushings, interrupters

Support components, if present, such as battery, battery charger, capacitor-trip, heaters, thermostat, fuses, wiring, controller

Primary leads

Functional Importance

Critical

Functionally important, e.g., required for critical lines, e.g. feeding hospitals or large customers. These would normally be primary feeders.

Minor

Functionally not important, but economically important, e.g. for any of the following reasons: high frequency of resulting corrective maintenance, more expensive to replace or repair than to do preventive maintenance, has a high potential to cause the failure of other critical or economically important equipment. These would normally be lateral lines. If the failure is not functionally important and also not economically important this would correspond to Run-To-Failure, but these cases are excluded from the Template.

Duty Cycle

High

Reclosers experiencing 10 or more operations/cycles per year

Low

Reclosers experiencing less than 10 operations/cycles per year.

Service Condition

Severe

High or excessive humidity, excessive temperatures (high/low) or temperature variations, excessive environmental conditions (e.g. salt, corrosive, spray), high vibration.

Mild

Absence of the above conditions.

3.4.2 *PM Template and Task Description*

		Critical Functional Importance				Minor Functional Importance			
	Duty Cycle:	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
	Service Condition:	**Severe**	**Severe**	**Mild**	**Mild**	**Severe**	**Severe**	**Mild**	**Mild**
Thermographic Survey	See PM Application Note 3.4.2.1	3Y	3Y	3Y	3Y	AR	AR	AR	AR
Battery Replacement and Visual Inspection	See PM Application Note 3.4.2.2	4Y	4Y	4Y	4Y	4Y	4Y	4Y	4Y
Refurbishment	See PM Application Note 3.4.2.3	AR	AR	AR	AR	AR	AR	AR	AR
Functional Test	See PM Application Note 3.4.2.4	AR	AR	AR	AR	AR	AR	AR	AR

3.4.2.1 Thermographic Survey

Task Objective:

This task primarily looks at the condition of the bushings and electrical connections. The failure rate is not at all sensitive to the task interval.

Failure Locations and Causes:

Thermography mainly addresses external contamination and damage to bushings, coking on interrupter contacts, and, to a lesser degree poor connections or misalignment of the auxiliary contacts.

Progression of Degradation to Failure:

External contamination of the bushings is a medium-term wear-out mechanism, but occurs much more quickly in certain environments. The other degradation mechanisms mentioned above are essentially random.

Fault Discovery and Intervention:

To remain maximally effective for the above failure mechanisms, this task would need to be performed a lot more frequently, but this is clearly not cost effective. This task has only a small effect on reliability.

The Scope of the Thermographic Survey is as Follows:

- Perform an IR scan of the recloser and its attachments
- Compare results with previous surveys and with adjacent tanks

3.4.2.2 Battery Replacement and Visual Inspection

Task Objective:

The main objective of this task is to replace the battery. There is some opportunity for interval extension as the failure rate is only moderately affected by this task.

Failure Locations and Causes:

This task primarily addresses the need to replace the battery, check condition of the battery charger, and to find contaminated or damaged bushings. In addition, there is some chance of finding a failed controller or damaged insulation on the primary conductor.

Progression of Degradation to Failure:

Most of these degradation mechanisms are of the wear-out type with an expected time to first failure of a few years up to about 10 years. Animal damage to bushings and the primary conductor is random.

Fault Discovery and Intervention:

The battery normally needs to be replaced at about a 4 year interval. This is the main influence on the task interval. There is little reason to make the interval shorter than that required for battery replacement, except in areas with rapid external contamination of the bushings, an especially high incidence of animal damage, or where a high rate of cycling requires more frequent status monitoring of the recloser.

3.4.2.3 The Scope of Battery Replacement and Visual Inspection is as Follows:

- Record the number of operating cycles
- Verify that signage is present and correct
- Replace the battery
- Verify the battery charger is operational
- Verify that the cabinet heater and thermostat are operable
- Check for chipped, cracked or dirty bushings
- Verify that animal guards are in place
- Check the tank for external evidence of leaks
- Verify proper oil level, and condition if visible
- Note controller alarms and indicators, if present
- Observe the general condition of all associated equipment

3.4.2.4 Refurbishment

Task Objective:

This task reduces the risk to the distribution system from end-of-life failure mechanisms that can not cost-effectively be repaired in-place. This is an on-condition task.

Failure Locations and Causes:

The refurbishment task essentially renews all subcomponents.

Progression of Degradation to Failure:

Refurbishment is focused on subcomponents that reach the end-of-life condition. These are mainly associated with the oil, oil or hydraulic pump, tank, interrupter, and battery charger.

Fault Discovery and Intervention:

This replacement task would normally be performed when an indicator, based on the number of cycles and the fault currents, shows that end-of-life has been reached.

The Scope of Refurbishment is as Follows:

- Replace the existing recloser with a new or rebuilt unit
- Perform all items of the Battery Replacement and Visual Inspection task
- Perform a functional test

3.4.2.5 Functional Test

Task Objective:

This task reduces the risk to the distribution system from end-of-life and other failure causes that have already occurred. The task interval is not a very strong influence on reliability, providing significant potential for interval extension.

Failure Locations and Causes:

The Functional Test mainly addresses external contamination on the bushings, a failed battery or battery charger, and a failed controller, as well as a wide range of other mechanisms.

Progression of Degradation to Failure:

These degradation mechanisms are wear-out mechanisms with an expected time to first failure of a few years in severe conditions.

Fault Discovery and Intervention:

The nature of this task means that it is mainly a failure finding task that prevents prolonged exposure of the system to a failed recloser. The "AR" in the Template suggests that this task would not normally be performed by most utilities. However, if performed yearly as the only task, it provides more than 80% of the reliability benefit of the complete recommended program. It would be even more effective if it included a scheduled battery change-out at 4 years.

The Scope of Functional Test is as Follows:

- Perform switching to transfer the load
- Inspect the control cabinet for abnormal conditions
- Perform the open/close operation on the recloser
- Return to normal service

3.4.3 *Failure Locations, Degradation Mechanisms, and PM Strategies*

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Thermographic Survey	Battery Replacement and Visual Inspection	Refurbishment	Functional Test
Animal Guards	Missing	Personnel error	R	H	H	H	H

Aux/AB Switch	High resistance connections	Contamination, moisture	R	L		H	M
Aux/AB Switch	Out of adjustment	Duty cycle, normal wear	R			H	H
Battery	Loss of Charge	Age	UW4_5		H	H	M

Failure Location	**Degradation Mechanism**	**Degradation Influence**	**Time Code**	**Thermographic Survey**	**Battery Replacement and Visual Inspection**	**Refurbishment**	**Functional Test**
Battery Charger	Damaged or failed	Age	UW10_12		H	H	M
Bushings - Solid	External contamination	Dirt, salt, environmental conditions	UW5	M	M	H	H
Bushings - Solid	External damage	Animal attack	R	L	H	H	M
Bushings - Solid	Loss of BIL	Chipped or cracked porcelain	R	M	M	H	H
Bushings - Solid	Loss of BIL	Voltage surges (e.g. lightning strikes)	R	L		H	L
Cabinet heater	Open	Aging	UW40		M	H	M
Capacitor Trip	Loss of dielectric	Age	UW20_30			H	M
Close and Trip Coils	Open coil	Aging	R			H	H
Close and Trip Solenoids	Bound linkages	Dirt, contamination, lack of use, failed lubricant	W20			H	H
Close and Trip Solenoids	Bound plunger	Dirt, contamination	R			H	H
Conductor - primary	Damaged insulation	Animal attack	R		H	H	M
Conductor - primary	Loose connections	Age	UW40	H		H	L
Controller	Failed	Age, temperature	UW10_15		M	H	H

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Thermographic Survey	Battery Replacement and Visual Inspection	Refurbishment	Functional Test
Controller	Improper Coordination	Improper setup	R			H	M
Current Transformer	Open coil	Age	R			H	
Fuse - control	Blown	Aging, overload	R			H	H
Fuse - control	Loose / corroded holders	Contamination , heat	R			H	H
Interrupter	Erosion of arcing and main contacts	Fault current interruptions	W5_8			H	
Interrupter	Erosion of arcing contacts	Normal wear	UW8_12			H	
Interrupter	Main and Arcing Contact Coking	Gas in oil from contact overheating	R	M		H	
Interrupter	Misaligned contacts	Personnel error	R	M		H	
Interrupter	Misaligned contacts	Worn linkages	UW40	M		H	
Lift Rod and Guides	Cracked or broken	Contact misalignment	R			H	L
Lift Rod and Guides	Warped	Water	R			H	L
Linkage	Out of adjustment	Normal wear	R			H	M
Linkage	Seized bearings	Lack of lubrication	W8_12			H	M
Linkage	Worn bearings	Normal wear	UW40			H	L
Oil	Contamination	Gassing from contact overheating	R			H	
Oil	Contamination	Gassing from fault interruption	R			H	

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Thermographic Survey	Battery Replacement and Visual Inspection	Refurbishment	Functional Test
Oil	Loss of dielectric	Particulates (carbon, metal, fiber)	UW10			H	
Oil	Loss of dielectric	Water	R			H	
Oil	Low oil level	Leaks	R		M	H	M
Oil/Hydraulic Pump Piston	Plugged orifice	Dirt, wear particles, water	UW10			H	
Tank	Cracked weld, leak	Manufacturing defect	R		M	H	L
Tank	Internal contamination	Particulates (carbon, metal, fiber)	UW10			H	
Tank	Internal contamination	Water ingress	R			H	
Tank Liner	Disbondment	Water ingress	R			H	
Thermostat	Drift	Normal wear	R			H	
Thermostat	Inoperable	Aging	UW40		M	H	
Wiring - control	Loose connections	Heat	UW20			H	M

3.5 Distribution Recloser - Oil-filled Vacuum Bottle

3.5.1 *Definitions: Boundary, Criticality, Duty Cycle, and Service Condition*

Boundary Definition

Tank or tanks, vacuum bottles, operating mechanism, aux switches, bushings

Support components, if present, such as battery, battery charger, capacitor-trip, heaters, thermostat, fuses, wiring, controller

Functional Importance

Critical

Functionally important, e.g., required for critical lines, e.g. feeding hospitals or large customers. These would normally be primary feeders.

Minor

Functionally not important, but economically important, e.g. for any of the following reasons: high frequency of resulting corrective maintenance, more expensive to replace or repair than to do preventive maintenance, has a high potential to cause the failure of other critical or economically important equipment. These would normally be lateral lines. If the failure is not functionally important and also not economically important this would correspond to Run-To-Failure, but these cases are excluded from the Template.

Duty Cycle

High

Reclosers experiencing 10 or more operations/cycles per year

Low

Reclosers experiencing less than 10 operations/cycles per year.

Service Condition

Severe

High or excessive humidity, excessive temperatures (high/low) or temperature variations, excessive environmental conditions (e.g. salt, corrosive, spray), high vibration.

Mild

Absence of the above conditions.

3.5.2 *PM Template and Task Description*

		Critical Functional Importance				Minor Functional Importance			
	Duty Cycle:	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
	Service Condition:	**Severe**	**Severe**	**Mild**	**Mild**	**Severe**	**Severe**	**Mild**	**Mild**
Thermographic Survey	See PM Application Note 3.5.2.1	3Y	3Y	3Y	3Y	AR	AR	AR	AR

Battery Replacement and Visual Inspection	See PM Application Note 3.5.2.2	4Y	4Y	4Y	4Y	4Y	4Y	4Y	4Y
Refurbishment	See PM Application Note 3.5.2.3	AR	AR	AR	AR	AR	AR	AR	AR
Functional Test	See PM Application Note 3.5.2.4	AR	AR	AR	AR	AR	AR	AR	AR

3.5.2.1 Thermographic Survey

Task Objective:

This task primarily looks at the condition of the bushings and electrical connections. The task interval is not strongly related to the underlying failure mechanisms.

Failure Locations and Causes:

Thermography mainly addresses external contamination and damage to bushings, poor connections or misalignment of the auxiliary contacts, and a poor connection on the primary conductor.

Progression of Degradation to Failure:

External contamination of the bushings is a medium-term wear-out mechanism, but occurs much more quickly in certain environments. Most of the other degradation mechanisms mentioned above are essentially random.

Fault Discovery and Intervention:

To remain maximally effective for the above failure mechanisms this task would need to be performed a lot more frequently, but this is clearly not cost effective. This task has almost no effect on reliability.

The Scope of the Thermographic Survey is as Follows:

- Perform an IR scan of the recloser and its attachments
- Compare results with previous surveys and with adjacent tanks

3.5.2.2 Battery Replacement and Visual Inspection

Task Objective:

The main objective of this task is to replace the battery. There is some opportunity for interval extension as the failure rate is only moderately affected by this task.

Failure Locations and Causes:

This task primarily addresses the need to replace the battery, check condition of the battery charger, and to find contaminated or damaged bushings. In addition, there is some chance of finding a failed controller or damaged insulation on the primary conductor.

Progression of Degradation to Failure:

Most of these degradation mechanisms are of the wear-out type with an expected time to first failure of a few years up to about 10 years. Animal damage to bushings and the primary conductor is random.

Fault Discovery and Intervention:

The battery normally needs to be replaced at about a 4 year interval. This is the main influence on the task interval. There is little reason to make the interval shorter than that required for battery replacement, except in areas with rapid external contamination of the bushings, an especially high incidence of animal damage, or where a high rate of cycling requires more frequent status monitoring of the recloser.

The Scope of Battery Replacement and Visual Inspection is as Follows:

- Record the number of operating cycles
- Verify that signage is present and correct
- Replace the battery
- Verify the battery charger is operational
- Verify that the cabinet heater and thermostat are operable
- Check for chipped, cracked or dirty bushings
- Verify that animal guards are in place
- Check the tank for external evidence of leaks
- Verify proper oil level, and condition if visible
- Note controller alarms and indicators, if present
- Observe the general condition of all associated equipment

3.5.2.3 Refurbishment

Task Objective:

This task reduces the risk to the distribution system from end-of-life failure mechanisms that can not cost-effectively be repaired in-place. This is an on-condition task.

Failure Locations and Causes:

The refurbishment task essentially renews all subcomponents.

Progression of Degradation to Failure:

Refurbishment is focused on subcomponents that reach the end-of-life condition. These are mainly associated with the battery and battery charger, tank, close and trip solenoids, and a wide range of other components.

Fault Discovery and Intervention:

This replacement task would normally be performed when an indicator, based on the number of cycles and the fault currents, shows that end-of-life has been reached.

The Scope of Refurbishment is as Follows:

- Replace the existing recloser with a new or rebuilt unit
- Perform all items of the Battery Replacement and Visual Inspection task
- Perform a functional test

3.5.2.4 Functional Test

Task Objective:

This task reduces the risk to the distribution system from end-of-life and other failure causes that have already occurred. The task interval is not a very strong influence on reliability, providing significant potential for interval extension.

Failure Locations and Causes:

The Functional Test mainly addresses external contamination on the bushings, a failed battery or battery charger, and a failed controller, as well as a wide range of other mechanisms.

Progression of Degradation to Failure:

These degradation mechanisms are wear-out mechanisms with an expected time to first failure of a few years in severe conditions.

Fault Discovery and Intervention:

The nature of this task means that it is mainly a failure finding task that prevents prolonged exposure of the system to a failed recloser. The "AR" in the Template suggests that this task would not normally be performed by most utilities. However, if performed yearly as the only task, it provides about 90% of the reliability benefit of the complete recommended program. It would be even more effective if it included a scheduled battery change-out at 4 years.

The Scope of Functional Test is as Follows:

- Perform switching to transfer the load
- Inspect the control cabinet for abnormal conditions
- Perform the open/close operation on the recloser
- Return to normal service

3.5.3 *Failure Locations, Degradation Mechanisms, and PM Strategies*

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Thermographic Survey	Battery Replacement and Visual Inspection	Refurbishment	Functional Test
Animal Guards	Missing	Personnel error	R	H	H	H	H
Aux/AB Switch	High resistance connections	Contamination, moisture	R	L		H	M
Aux/AB Switch	Out of adjustment	Duty cycle, normal wear	R			H	H
Battery	Loss of Charge	Age	UW4_5		H	H	M
Battery Charger	Damaged or failed	Age	UW10_12		H	H	H
Bushings - Solid	External contamination	Dirt, salt, environmental conditions	UW5	M	M	H	H
Bushings - Solid	External damage	Animal attack	R	L	H	H	M
Bushings - Solid	Loss of BIL	Chipped or cracked porcelain	R	M	M	H	H
Bushings - Solid	Loss of BIL	Voltage surges (e.g. lightning strikes)	R	L		H	L
Cabinet heater	Open	Aging	UW40		M	H	M
Capacitor Trip	Loss of dielectric	Age	UW20_30			H	M
Close and Trip Coils	Open coil	Aging	R			H	H
Close and Trip Solenoids	Bound linkages	Dirt, contamination, lack of use, failed lubricant	W20			H	H
Close and Trip Solenoids	Bound plunger	Dirt, contamination	R			H	H

Conductor - primary	Damaged insulation	Animal attack	UW40		H	H	M
Cabinet heater	Open	Aging	UW40		M	H	M

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Thermographic Survey	Battery Replacement and Visual Inspection	Refurbishment	Functional Test
Capacitor Trip	Loss of dielectric	Age	UW20_30			H	M
Close and Trip Coils	Open coil	Aging	R			H	H
Close and Trip Solenoids	Bound linkages	Dirt, contamination, lack of use, failed lubricant	W20			H	H
Close and Trip Solenoids	Bound plunger	Dirt, contamination	R			H	H
Conductor - primary	Damaged insulation	Animal attack	UW40		H	H	M
Conductor - primary	Loose connections	Age	UW40	H		H	L
Controller	Failed	Age, temperature	UW10_15		M	H	H
Controller	Improper Coordination	Improper setup	R			H	M
Current Transformer	Open coil	Age	R			H	
Fuse - control	Blown	Aging, overload	R			H	H
Fuse - control	Loose / corroded holders	Contamination, heat	R			H	H
Lift Rod and Guides	Cracked or broken	Contact misalignment	R			H	L
Lift Rod and Guides	Warped	Water	R			H	L
Linkage	Out of adjustment	Normal wear	R			H	M
Linkage	Seized bearings	Lack of lubrication	W8_12			H	M
Linkage	Worn bearings	Normal wear	UW40			H	L
Main current contacts	Wear	Normal wear	UW40			H	

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Thermographic Survey	Battery Replacement and Visual Inspection	Refurbishment	Functional Test
Oil	Loss of dielectric	Particulates (carbon, metal, fiber)	UW20			H	
Oil	Loss of dielectric	Water	R			H	
Oil	Low oil level	Leaks	R		M	H	M
Tank	Cracked weld, leak	Manufacturing defect	R		M	H	L
Tank	Internal contamination	Particulates (carbon, metal, fiber)	UW10			H	
Tank	Internal contamination	Water ingress	R			H	
Tank Liner	Disbondment	Water ingress	R			H	
Thermostat	Drift	Normal wear	R			H	
Thermostat	Inoperable	Aging	UW40		M	H	
Vacuum Bottle	Loss of vacuum	Leaks	R			H	
Wiring - control	Loose connections	Heat	UW20			H	M

3.6 Distribution Recloser - SF_6-Filled Vacuum Bottle

3.6.1 *Definitions: Boundary, Criticality, Duty Cycle, and Service Condition*

Boundary Definition

Tank or tanks, SF_6 gas bottles, operating mechanism, aux switches, bushings

Support components, if present, such as battery, battery charger, capacitor-trip, heaters, thermostat, fuses, wiring, controller.

Functional Importance

Critical

Functionally important, e.g., required for critical lines, e.g. feeding hospitals or large customers. These would normally be primary feeders.

Minor

Functionally not important, but economically important, e.g. for any of the following reasons: high frequency of resulting corrective maintenance, more expensive to replace or repair than to do preventive maintenance, has a high potential to cause the failure of other critical or economically important equipment. These would normally be lateral lines. If the failure is not functionally important and also not economically important this would correspond to Run-To-Failure, but these cases are excluded from the Template.

Duty Cycle

High

Reclosers experiencing 10 or more operations/cycles per year

Low

Reclosers experiencing less than 10 operations/cycles per year.

Service Condition

Severe

High or excessive humidity, excessive temperatures (high/low) or temperature variations, excessive environmental conditions (e.g. salt, corrosive, spray), high vibration.

Mild

Absence of the above conditions.

3.6.2 *PM Template and Task Description*

		Critical Functional Importance				Minor Functional Importance			
	Duty Cycle:	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
	Service Condition:	**Severe**	**Severe**	**Mild**	**Mild**	**Severe**	**Severe**	**Mild**	**Mild**
Thermographic Survey	See PM Application Note 3.6.2.1	3Y	3Y	3Y	3Y	AR	AR	AR	AR
Battery Replacement and Visual Inspection	See PM Application Note 3.6.2.2	4Y	4Y	4Y	4Y	4Y	4Y	4Y	4Y
Functional Test	See PM Application Note 3.6.2.3	AR	AR	AR	AR	AR	AR	AR	AR

3.6.2.1 Thermographic Survey

Task Objective:

This task primarily looks at the condition of the bushings and electrical connections. The task interval is not strongly related to the underlying failure mechanisms.

Failure Locations and Causes:

Thermography mainly addresses external contamination and damage to bushings, poor connections or misalignment of the auxiliary contacts and a poor connection on the primary conductor.

Progression of Degradation to Failure:

External contamination of the bushings is a medium-term wear-out mechanism, but occurs much more quickly in certain environments. Most of the other degradation mechanisms mentioned above are essentially random.

Fault Discovery and Intervention:

To remain maximally effective for the above failure mechanisms this task would need to be performed a lot more frequently, but this is clearly not cost effective. This task has almost no effect on reliability.

The Scope of the Thermographic Survey is as Follows:

- Perform an IR scan of the recloser and its attachments
- Compare results with previous surveys and with adjacent tanks

3.6.2.2 Battery Replacement and Visual Inspection

Task Objective:

The main objective of this task is to replace the battery. There is some opportunity for interval extension as the failure rate is only moderately affected by this task.

Failure Locations and Causes:

This task primarily addresses the need to replace the battery, check condition of the battery charger, and to find contaminated or damaged bushings. In addition, there is some chance of finding a failed controller or damaged insulation on the primary conductor.

Progression of Degradation to Failure:

The battery normally needs to be replaced at about a 4 year interval. This is the main influence on the task interval. There is little reason to make the interval shorter than that required for battery replacement, except in areas with rapid external contamination of the bushings, an especially high incidence of animal damage, or where a high rate of cycling requires more frequent status monitoring of the recloser.

Fault Discovery and Intervention:

The battery normally needs to be replaced at about a 4 year interval. This is the main influence on the task interval. There is little reason to make the interval shorter than that required for battery replacement, except in areas with rapid external contamination of the bushings, an especially high incidence of animal damage, or where a high rate of cycling requires more frequent status monitoring of the recloser.

The Scope of Battery Replacement and Visual Inspection is as Follows:

- Record the number of operating cycles
- Verify that signage is present and correct
- Replace the battery
- Verify the battery charger is operational
- Verify that the cabinet heater and thermostat are operable
- Check for chipped, cracked or dirty bushings
- Verify that animal guards are in place
- Check the tank for external evidence of leaks
- Verify proper oil level, and condition if visible
- Note controller alarms and indicators, if present
- Observe the general condition of all associated equipment

3.6.2.3 Functional Test

Task Objective:

This task reduces the risk to the distribution system from end-of-life and other failure causes that have already occurred. The task interval is not a very strong influence on reliability, providing significant potential for interval extension.

Failure Locations and Causes:

The Functional Test mainly addresses external contamination on the bushings, a failed battery or battery charger, and a failed controller, as well as a wide range of other mechanisms.

Progression of Degradation to Failure:

These degradation mechanisms are wear-out mechanisms with an expected time to first failure of a few years in severe conditions.

Fault Discovery and Intervention:

The nature of this task means that it is mainly a failure finding task that prevents prolonged exposure of the system to a failed recloser. The "AR" in the Template suggests that this task would not normally be performed by most utilities. However, if performed yearly as the only task, it provides about 90% of the reliability benefit of the complete recommended program. It would be even more effective if it included a scheduled battery change-out at 4 years.

The Scope of Functional Test is as Follows:

- Perform switching to transfer the load
- Inspect the control cabinet for abnormal conditions
- Perform the open/close operation on the recloser
- Return to normal service

3.6.3 *Failure Locations, Degradation Mechanisms, and PM Strategies*

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Thermographic Survey	Battery Replacement and Visual Inspection	Functional Test
Animal Guards, if present	Missing	Personnel error	R	H	H	H
Aux/AB Switch	High resistance connections	Contamination, moisture	R	L		M
Aux/AB Switch	Out of adjustment	Duty cycle, normal wear	R			H
Battery	Loss of Charge	Age	UW4_5		H	M
Battery Charger	Damaged or failed	Age	UW10_12		H	M
Bushings - Solid	External contamination	Dirt, salt, environmental conditions	UW5	M	M	H
Bushings - Solid	External damage	Animal attack	R	L	H	M
Bushings - Solid	Loss of BIL	Chipped or cracked	R	M	M	H
Bushings - Solid	Loss of BIL	Voltage surges (e.g. lightning strikes)	R	L		L
Cabinet heater	Open	Aging	UW40		M	M

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Thermographic Survey	Battery Replacement and Visual Inspection	Functional Test
Close and Trip Coils	Open coil	Aging	R			H
Close and Trip Solenoids	Bound linkages	Dirt, contamination, lack of use, failed lubricant	W20			H
Close and Trip Solenoids	Bound plunger	Dirt, contamination	R			H
Conductor - primary	Damaged insulation	Animal attack	R		H	M
Conductor - primary	Loose connections	Age	UW40	H		L
Controller	Failed	Age, temperature	UW10_15		M	H
Controller	Improper Coordination	Improper setup	R			M
Current Transformer	Open coil	Age	R			
Fuse - control	Blown	Aging, overload	R			H
Fuse - control	Loose / corroded holders	Contamination, heat	R			H
Linkage	Out of adjustment	Normal wear	R			M
Main current contacts	Wear	Normal wear	UW40			
Operating Rods	Cracked or broken	Contact misalignment	R			M
SF6 gas	Low gas pressure	Leaks, e.g. rupture disk cracked	R		H	H
Tank	Cracked weld, leak	Manufacturing defect	R		M	L
Thermostat	Drift	Normal wear	R			
Thermostat	Inoperable	Aging	UW40		M	
Wiring - control	Loose connections	Heat	UW20			M

3.7 Distribution Recloser - Solid Dielectric

3.7.1 *Definitions: Boundary, Criticality, Duty Cycle, and Service Condition*

Boundary Definition

Tank or tanks, vacuum bottles, operating mechanism, aux switches, bushings

Support components, if present, such as battery, battery charger, capacitor-trip, heaters, thermostat, fuses, wiring, controller

Functional Importance

Critical

Functionally important, e.g., required for critical lines, e.g. feeding hospitals or large customers. These would normally be primary feeders.

Minor

Functionally not important, but economically important, e.g. for any of the following reasons: high frequency of resulting corrective maintenance, more expensive to replace or repair than to do preventive maintenance, has a high potential to cause the failure of other critical or economically important equipment. These would normally be lateral lines. If the failure is not functionally important and also not economically important this would correspond to Run-To-Failure, but these cases are excluded from the Template.

Duty Cycle

High

Reclosers experiencing 10 or more operations/cycles per year

Low

Reclosers experiencing less than 10 operations/cycles per year.

Service Condition

Severe

High or excessive humidity, excessive temperatures (high/low) or temperature variations, excessive environmental conditions (e.g. salt, corrosive, spray), high vibration.

Mild

Absence of the above conditions.

3.7.2 PM Template and Task Description

		Critical Functional Importance				Minor Functional Importance			
	Duty Cycle:	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
	Service Condition:	**Severe**	**Severe**	**Mild**	**Mild**	**Severe**	**Severe**	**Mild**	**Mild**
Thermographic Survey	See PM Application Note 3.7.2.1	3Y	3Y	3Y	3Y	AR	AR	AR	AR
Battery Replacement and Visual Inspection	See PM Application Note 3.7.2.2	4Y	4Y	4Y	4Y	AR	AR	AR	AR
Functional Test	See PM Application Note 3.7.2.3	AR	AR	AR	AR	AR	AR	AR	AR

3.7.2.1 Thermographic Survey

Task Objective:

This task primarily looks at the condition of the bushing interrupter unit and electrical connections. The task interval is not strongly related to the underlying failure mechanisms.

Failure Locations and Causes:

Thermography mainly addresses external contamination and damage to the bushing interrupter unit, poor connections or misalignment of the auxiliary contacts and a poor connection on the primary conductor.

Progression of Degradation to Failure:

External contamination of the bushing interrupter unit is a medium-term wear-out mechanism, but occurs much more quickly in certain environments. Most of the other degradation mechanisms mentioned above are essentially random.

Fault Discovery and Intervention:

To remain maximally effective for the above failure mechanisms this task would need to be performed a lot more frequently, but this is clearly not cost effective. This task has almost no effect on reliability.

The Scope of the Thermographic Survey is as Follows:

- Perform an IR scan of the recloser and its attachments

- Compare results with previous surveys and with adjacent tanks

3.7.2.2 Battery Replacement and Visual Inspection

Task Objective:

The main objective of this task is to replace the battery. There is some opportunity for interval extension as the failure rate is only moderately affected by this task.

Failure Locations and Causes:

This task primarily addresses the need to replace the battery, check condition of the battery charger, and to find contaminated or damaged bushings. In addition, there is some chance of finding a failed controller or damaged insulation on the primary conductor.

Progression of Degradation to Failure:

The battery normally needs to be replaced at about a 4 year interval. This is the main influence on the task interval. There is little reason to make the interval shorter than that required for battery replacement, except in areas with rapid external contamination of the bushings, an especially high incidence of animal damage, or where a high rate of cycling requires more frequent status monitoring of the recloser.

Fault Discovery and Intervention:

The battery normally needs to be replaced at about a 4 year interval. This is the main influence on the task interval. There is little reason to make the interval shorter than that required for battery replacement, except in areas with rapid external contamination of the bushings, an especially high incidence of animal damage, or where a high rate of cycling requires more frequent status monitoring of the recloser.

The Scope of Battery Replacement and Visual Inspection is as Follows:

- Record the number of operating cycles
- Verify that signage is present and correct
- Replace the battery
- Verify the battery charger is operational
- Verify that the cabinet heater and thermostat are operable
- Check for chipped, cracked or dirty bushings
- Verify that animal guards are in place
- Check the tank for external evidence of leaks
- Verify proper oil level, and condition if visible
- Note controller alarms and indicators, if present
- Observe the general condition of all associated equipment

3.7.2.3 Functional Test

Task Objective:

This task reduces the risk to the distribution system from end-of-life and other failure causes that have already occurred. The task interval is not a very strong influence on reliability, providing significant potential for interval extension.

Failure Locations and Causes:

The Functional Test mainly addresses external contamination on the bushings, a failed battery or battery charger, and a failed controller, as well as a wide range of other mechanisms.

Progression of Degradation to Failure:

These degradation mechanisms are wear-out mechanisms with an expected time to first failure of a few years in severe conditions.

Fault Discovery and Intervention:

The nature of this task means that it is mainly a failure finding task that prevents prolonged exposure of the system to a failed recloser. The "AR" in the Template suggests that this task would not normally be performed by most utilities. However, if performed yearly as the only task, it provides about 90% of the reliability benefit of the complete recommended program. It would be even more effective if it included a scheduled battery change-out at 4 years.

The Scope of Functional Test is as Follows:

- Perform switching to transfer the load
- Inspect the control cabinet for abnormal conditions
- Perform the open/close operation on the recloser
- Return to normal service

3.7.3 *Failure Locations, Degradation Mechanisms, and PM Strategies*

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Thermographic Survey	Battery Replacement and Visual Inspection	Functional Test
Animal Guards, if present	Missing	Personnel error	R	H	H	H
Aux/AB Switch	High resistance connections	Contamination, moisture	R	L		M
Aux/AB Switch	Out of adjustment	Duty cycle, normal wear	R			H
Battery	Loss of Charge	Age	UW4_5		H	M
Battery Charger	Damaged or failed	Age	UW10_12		H	M
Bushing Interrupter Unit	Degraded dielectric	Age	UW40	L		
Bushing Interrupter Unit	External contamination	Dirt, salt, environmental conditions	UW5	M	M	H
Bushing Interrupter Unit	External damage	Animal attack	R	L	L	M
Bushing Interrupter Unit	Loss of BIL	Chipped or cracked	R	M	M	H
Bushing Interrupter Unit	Loss of BIL	Voltage surges (e.g. lightning strikes)	R	L		L
Bushing Interrupter Unit	Loss of vacuum	Age	UW40			
Cabinet heater	Open	Aging	UW40		M	M
Close and Trip Coils	Open coil	Aging	R			H
Close and Trip Solenoids	Bound linkages	Dirt, contamination, lack of use, failed lubricant	W20			H
Close and Trip Solenoids	Bound plunger	Dirt, contamination	R			H
Conductor - primary	Damaged insulation	Animal attack	R		H	M

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Thermographic Survey	Battery Replacement and Visual Inspection	Functional Test
Conductor - primary	Loose connections	Age	UW40	H		L
Controller	Failed	Age, temperature	UW10_15		M	H
Controller	Improper Coordination	Improper setup	R			M
Current Transformer	Open coil	Age	R			
Fuse - control	Blown	Aging, overload	R			H
Fuse - control	Loose / corroded holders	Contamination, heat	R			H
Linkage	Out of adjustment	Normal wear	R			M
Main current contacts	Wear	Normal wear	UW40		L	L
Operating Rods	Cracked or broken	Contact misalignment	R			M
Thermostat	Drift	Normal wear	R			
Thermostat	Inoperable	Aging	UW40		M	
Wiring - control	Loose connections	Heat	UW20			M

3.8 Distribution Disconnect - Fused

3.8.1 *Definitions: Boundary, Criticality, Duty Cycle, and Service Condition*

Boundary Definition

Porcelain (insulating body), barrel, contacts, fuse, and mounting attachment.

Animal guards, if present

Primary connection

Functional Importance

Critical

Functionally important, e.g., required for critical lines, e.g. feeding hospitals or large customers. These would normally be primary feeders.

Minor

Functionally not important, but economically important, e.g. for any of the following reasons: high frequency of resulting corrective maintenance, more expensive to replace or repair than to do preventive maintenance, has a high potential to cause the failure of other critical or economically important equipment. These would normally be lateral lines. If the failure is not functionally important and also not economically important this would correspond to Run-To-Failure, but these cases are excluded from the Template.

Duty Cycle

High

Reclosers experiencing 200 or more operations/cycles per year

Low

Reclosers experiencing less than 200 operations/cycles per year.

Service Condition

Severe

High or excessive humidity, excessive temperatures (high/low) or temperature variations, excessive environmental conditions (e.g. salt, corrosive, spray), high vibration.

Mild

Absence of the above conditions.

3.8.2 PM Template and Task Description

		Critical Functional Importance				Minor Functional Importance			
	Duty Cycle:	High	Low	High	Low	High	Low	High	Low
	Service Condition:	Severe	Severe	Mild	Mild	Severe	Severe	Mild	Mild
Thermographic Survey	See PM Application Note 3.8.2.1	3Y	3Y	3Y	3Y	AR	AR	AR	AR
Replacement	See PM Application Note 3.8.2.2	AR	AR	AR	AR	AR	AR	AR	AR

3.8.2.1 Thermographic Survey

Task Objective:

This task primarily looks at the condition of the porcelain body and electrical connections. The task interval is not directly based on underlying failure data and may provide significant opportunity for interval extension.

Failure Locations and Causes:

This task can identify chipped or cracked porcelain bodies and those that have experienced flashover. It also identifies damaged insulation on the primary connection.

Progression of Degradation to Failure:

Chipped porcelain and damage to the primary connection is random, but flashover occurs only after a few years of accumulating contamination. The cracked porcelain is a manufacturing defect that affects only disconnects manufactured before about 1997.

Fault Discovery and Intervention:

The 3 year interval is reasonable to address external contamination and flashover, but is not directly derived from or associated with the random processes.

The Scope of the Thermographic Survey is as Follows:

- Perform an IR scan of the disconnect and its attachments
- Compare results with previous surveys and with adjacent disconnects

3.8.2.2 Replacement

Task Objective:

This task primarily addresses the issues raised by defective porcelain bodies for disconnects manufactured before 1997. This is therefore not a regularly scheduled task.

Failure Locations and Causes:

This task primarily addresses the issues raised by defective porcelain bodies for disconnects manufactured before 1997.

Progression of Degradation to Failure:

This is a fairly long-term wear-out degradation mechanism with an expected time to first failure of about 25 to 30 years. Thus the most urgent replacements are on the older units, or for those in high risk areas, or where frequent freeze-thaw cycles are prevalent.

Fault Discovery and Intervention:

There can be several possible different replacement policies:

- Replacement may be an on-condition activity based on finding cracked or broken porcelain.
- Porcelain cutouts introduced before 1997 may be replaced either:
    - only when cracked or damaged, or
    - at the first available opportunity whether damaged or not, or
    - as a blanket replacement only in high risk locations, e.g. high traffic, around schools, parks, hospitals, downtown, or poles that have to be climbed regularly, or
    - as a blanket replacement

The Scope of Replacement is as Follows:

- Inspect the disconnect for signs of cracking, damage, flash over
- Isolate disconnect from service
- Replace disconnect, as required
- Restore to service

3.8.3 *Failure Locations, Degradation Mechanisms, and PM Strategies*

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Thermographic Survey	Replacement

Animal guard	Missing	Installation error	R	H	H
Barrel	Deterioration	Age	UW20_30		H
Barrel	Deterioration	Moisture (usually from storing upside down)	W1_3		H
Connection - primary	Damaged	Animal attack	R	H	H
Connection - primary	Loose	Installation error	R	H	H
Contacts	Corroded	Arcing	R	L	H
Contacts	Loose	Improper fuse installation	R	H	H
Contacts	Misalignment	Manufacturing defect, Maintenance error	R	L	H
Fuse	Incorrect size	Personnel error	R		H
Mounting Bracket	Distorted	Installation error	R	L	H
Porcelain	Chipped	Hail damage, poor handling, gun shots	R	M	H
Porcelain	Cracks	Manufacturing defect allowing water ingress (particularly 1975 to 1980 manufacturer dates)	UW25_30	M	H
Porcelain	Flashover	Animal contact	R	M	H
Porcelain	Flashover	External contamination	W5	M	H

3.9 Distribution Lightning Arrestor - Silicon Carbide

3.9.1 *Definitions: Boundary, Criticality, Duty Cycle, and Service Condition*

Boundary Definition

Arrestor body, ground and line attachments.

Functional Importance

Critical

Functionally important, e.g., required for critical lines, e.g. feeding hospitals or large customers. These would normally be primary feeders.

Minor

Functionally not important, but economically important, e.g. for any of the following reasons: high frequency of resulting corrective maintenance, more expensive to replace or repair than to do preventive maintenance, has a high potential to cause the failure of other critical or economically important equipment. These would normally be lateral lines. If the failure is not functionally important and also not economically important this would correspond to Run-To-Failure, but these cases are excluded from the Template.

Duty Cycle

High

All lightning arresters are considered to be low duty cycle regardless of regional differences in lightning frequency.

Low

All lightning arresters are considered to be low duty cycle regardless of regional differences in lightning frequency.

Service Condition

Severe

High or excessive humidity, excessive temperatures (high/low) or temperature variations, excessive environmental conditions (e.g. salt, corrosive, spray), high vibration.

Mild

Absence of the above conditions.

3.9.2 PM Template and Task Description

		Critical Functional Importance				Minor Functional Importance			
	Duty Cycle:	High	Low	High	Low	High	Low	High	Low
	Service Condition:	Severe	Severe	Mild	Mild	Severe	Severe	Mild	Mild
Visual Inspection	See PM Application Note 3.9.2.1	NA	3Y	NA	3Y	NA	AR	NA	AR

3.9.2.1 Visual Inspection

Task Objective:

This task is performed to replace arrestors that can be observed to have failed. This is a failure finding task and the failure rate of the arresters is quite insensitive to the task interval.

Failure Locations and Causes:

Visual Inspection can identify insulation on the primary connection that has been damaged by animals, as well as arresters that have experienced flashover from external contamination or animal contact, or where the porcelain is chipped.

Progression of Degradation to Failure:

Damage from animals on primary connection insulation or arrester bodies is random, whereas flashover from an accumulation of external contamination will usually take at least 5 years. Chipped porcelain is caused by a variety of external events such as hail or gun shots, and is random.

Fault Discovery and Intervention:

This task may not be focused exclusively on lightning arrestors as these could be inspected as part of a patrol that would inspect all equipment on a pole. The task frequency will normally depend on the frequency of lightning.

The Scope of the Visual Inspection is as Follows:

- Verify that the arrestor appears to be in an operating condition
- Verify that animal guards are in place
- Verify that the primary and ground connections are in place
- Inspect the arrestor body for evidence of damage and flashover

3.9.3 *Failure Locations, Degradation Mechanisms, and PM Strategies*

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Visual Inspection
Animal guard	Missing	Installation error	R	H
Connection - ground	Loose or missing	Installation error	R	M
Connection - primary	Damaged	Animal attack	R	H
Connection - primary	Loose	Installation error	R	H
Porcelain	Chipped	Hail damage, poor handling, gun shots	R	M
Porcelain	Cracks	Manufacturing defect allowing water ingress (particularly 1975 to 1980 manufacturer dates)	R	M
Porcelain	Flashover	Animal contact	R	M
Porcelain	Flashover	External contamination	W5	M
Semiconducting Stack	Shorted	Aging	UW30	
Semiconducting Stack	Shorted	Lightning	R	M
Semiconducting Stack	Shorted	Water ingress	UW13_20	

3.10 Distribution Lightning Arrestor - Silicon Carbide

3.10.1 *Definitions: Boundary, Criticality, Duty Cycle, and Service Condition*

Boundary Definition

Arrestor body, ground and line attachments.

Functional Importance

Critical

Functionally important, e.g., required for critical lines, e.g. feeding hospitals or large customers. These would normally be primary feeders.

Minor

Functionally not important, but economically important, e.g. for any of the following reasons: high frequency of resulting corrective maintenance, more expensive to replace or repair than to do preventive maintenance, has a high potential to cause the failure of other critical or economically important equipment. These would normally be lateral lines. If the failure is not functionally important and also not economically important this would correspond to Run-To-Failure, but these cases are excluded from the Template.

Duty Cycle

High

All lightning arresters are considered to be low duty cycle regardless of regional differences in lightning frequency.

Low

All lightning arresters are considered to be low duty cycle regardless of regional differences in lightning frequency.

Service Condition

Severe

High or excessive humidity, excessive temperatures (high/low) or temperature variations, excessive environmental conditions (e.g. salt, corrosive, spray), high vibration.

Mild

Absence of the above conditions.

3.10.2 *PM Template and Task Description*

		Critical Functional Importance				Minor Functional Importance			
	Duty Cycle:	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
	Service Condition:	**Severe**	**Severe**	**Mild**	**Mild**	**Severe**	**Severe**	**Mild**	**Mild**
Visual Inspection	See PM Application Note 3.10.2.1	NA	3Y	NA	3Y	NA	AR	NA	AR

3.10.2.1 Visual Inspection

Task Objective:

This task is performed to replace arrestors that can be observed to have failed. This is a failure finding task and the failure rate of the arresters is quite insensitive to the task interval.

Failure Locations and Causes:

Visual Inspection can identify insulation on the primary connection that has been damaged by animals, as well as arresters that have experienced flashover from external contamination or animal contact.

Progression of Degradation to Failure:

Damage from animals on primary connection insulation or arrester bodies is random, whereas flashover from an accumulation of external contamination will usually take at least 5 to 8 years.

Fault Discovery and Intervention:

This task may not be focused exclusively on lightning arrestors as these could be inspected as part of a patrol that would inspect all equipment on a pole. The task frequency will normally depend on the frequency of lightning.

The Scope of the Visual Inspection is as Follows:

- Verify that the arrestor appears to be in an operating condition
- Verify that animal guards are in place
- Verify that the primary and ground connections are in place
- Inspect the arrestor body for evidence of damage and flashover

3.10.3 *Failure Locations, Degradation Mechanisms, and PM Strategies*

Failure Location	Degradation Mechanism	Degradation Influence	Time Code	Visual Inspection
Animal guard	Missing	Installation error	R	H
Connection - ground	Loose or missing	Installation error	R	M
Connection - primary	Damaged	Animal attack	R	H
Connection - primary	Loose	Installation error	R	H
Porcelain	Chipped	Hail damage, poor handling, gun shots	R	M
Porcelain	Cracks	Manufacturing defect allowing water ingress (particularly 1975 to 1980 manufacturer dates)	R	M
Porcelain	Flashover	Animal contact	R	M
Porcelain	Flashover	External contamination	W5	M
Semiconducting Stack	Shorted	Aging	UW30	
Semiconducting Stack	Shorted	Lightning	R	M
Semiconducting Stack	Shorted	Water ingress	UW13_20	

REFERENCES

1. *Aging Assets Analysis System, V. 1.0.* EPRI, Palo Alto, CA: 2002. 1001872.
2. *Aging Assets Analysis System Version 1.5*. EPRI, Palo Alto, CA: 2003. 1001703.
3. *Asset Population Management Model with Testing for Managing Aging Power Delivery Assets*. EPRI, Palo Alto, CA: 2004. 1008562.
4. *Asset Population Management and Testing – Methodology Extensions*, EPRI, Palo Alto, CA: 2005. 1011665
5. *Estimating Reliability of Critical Distribution System Components.* EPRI, Palo Alto, CA: 2003. 1001704.
6. *A Review of the Reliability of Electric Distribution System Components: EPRI White Paper*. EPRI, Palo Alto, CA: 2001. 1001873.
7. *Managing Aging Distribution System Assets.* EPRI, Palo Alto, CA: 2000. 1000422.
8. *Guidelines for Intelligent Asset Replacement: Volume I.* EPRI, Palo Alto, CA: 2003. 1002086.
9. *Guidelines for Intelligent Asset Replacement: Volume 2 – Wood Poles.* EPRI, Palo Alto, CA: 2004. 1002087.
10. *Guidelines for Intelligent Asset Replacement: Volume 3 – Underground Distribution Cables.* EPRI, Palo Alto, CA: 2005. 1010740
11. *Equipment Failure Model and Data for Underground Distribution Cables.* EPRI, Palo Alto, CA: 2004. 1008560.
12. *Equipment Failure Model and Data for Wood Utility Poles*. EPRI, Palo Alto, CA: 2004. 1008561.
13. *PMBD: Preventive Maintenance Basis Database, Version 5.1.1*. EPRI, Palo Alto, CA: 2004. 1010919.
14. *Asset Performance Database: A Recommended Approach for Data Modeling to Facilitate Power Delivery Asset Management*, EPRI, Palo Alto, CA: 2005. 1008553.
15. *Nuclear Asset Management Database – Phase 2: Prototype Long-term Asset Management Database (LAMDA)*, EPRI, Palo Alto, CA: 2004. 1009633.
16. *Risk-based least-cost strategy for managing risk associated with porcelain cutout asset in BC Hydro System,* 8th International Conference on Probabilistic Methods Applied to Power Systems, Iowa, Sept. 2004.

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