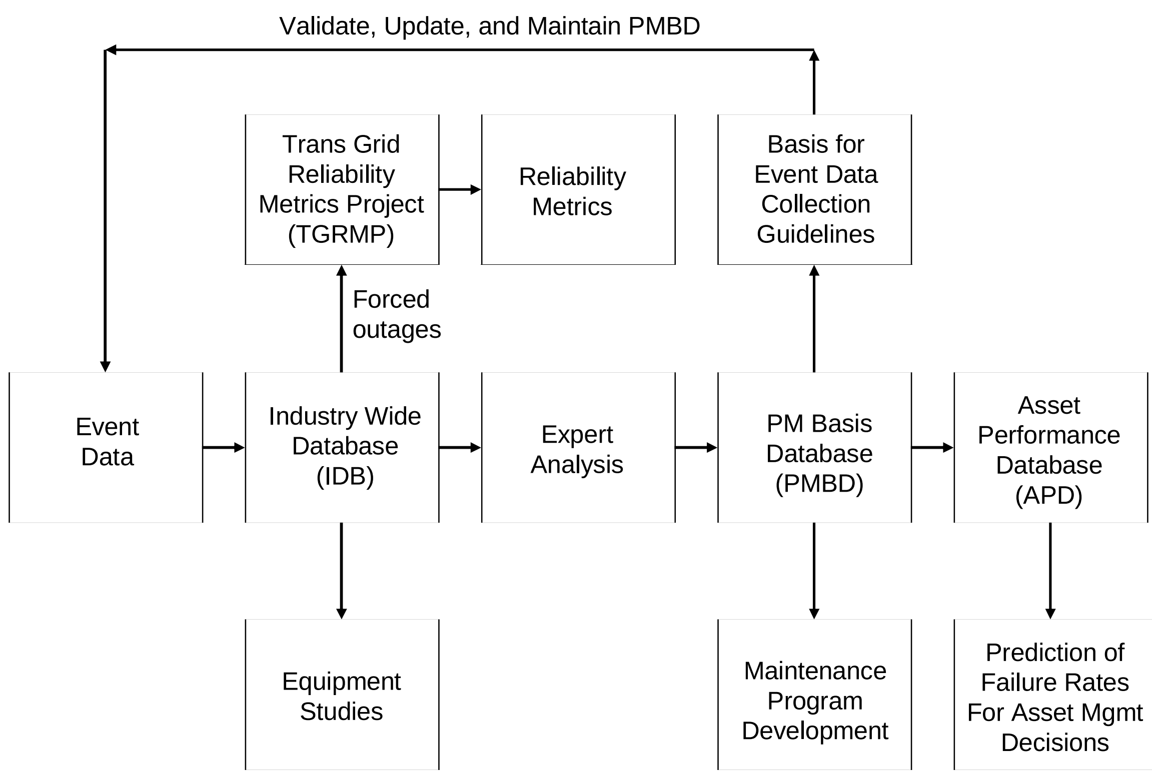
Asset Performance Database

A Recommended Approach for Data Modeling to Facilitate Power Delivery Asset Management

Technical Report



Asset Performance Database

A Recommended Approach for Data Modeling to Facilitate Power Delivery Asset Management

1008553

Final Report, May 2005

EPRI Project Manager
W. Parkinson

Electric Power Research Institute • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

EPRI

ORDERING INFORMATION

Requests for copies of this report should be directed to EPRI Orders and Conferences, 1355 Willow Way, Suite 278, Concord, CA 94520, (800) 313-3774, press 2 or internally x5379, (925) 609-9169, (925) 609-1310 (fax).

CITATIONS

This report was prepared by

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

Principal Investigator
W. Parkinson

This report describes research sponsored by Electric Power Research Institute (EPRI).

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

Asset Performance Database: A Recommended Approach for Data Modeling to Facilitate Power Delivery Asset Management. EPRI, Palo Alto, CA: 2005. 1008553.

REPORT SUMMARY

Complexities and limitations of existing reliability data inhibit efficient asset management activities in the power delivery industry today. This report describes how EPRI's PM Basis Database (PMBD) method developed for the nuclear power industry can be applied to the power delivery industry to address these limitations.

Background

Much of the data collected today that asset managers need is difficult to use. Data is often collected in forms that are not electronic, while data that is available electronically is often stored in text or narrative forms, which are difficult to evaluate. Though some enterprise asset management systems provide the means of collecting data more efficiently, current implementations of these systems often suffer from lack of anticipation of asset managers' needs. These needs include easy access to asset performance data such as reliability estimates, return-to-service times, equipment health, and cost information. As a result, analyzing existing data to determine component failure rates can be a costly proposition. Because the data are limited to situations that have occurred in the past, the data does not enable asset managers to predict the impact on failure rates if the maintenance program is changed or if redesigned equipment or equipment employing new technologies is introduced. Quite clearly, using past data only allows asset managers to look back, when they need a way to look forward.

Objectives

- To identify and document an approach that effectively addresses reliability data limitations in the power delivery industry.
- To describe an overall method for applying this approach in the power delivery industry.
- To identify and prioritize the next steps needed to achieve this goal.

Approach

The project team conducted an informal review of existing methods of data modeling. This review quickly identified the PMBD method used in the nuclear power industry as the prime candidate to act as the basis for the APD approach to calculate asset performance data. Further investigation confirmed that this method is highly suitable for asset management needs, and that in fact, many of the equipment types already analyzed with the PMBD method are contained in power delivery systems (e.g., relays, breakers, transformers, etc.). The team then documented in this report the Asset Performance Database (APD) approach, which applies the PMBD method. After developing a plan for implementing the APD approach in the power delivery industry, the team summarized existing reliability data sources in an appendix to the report.

Results

This report documents the first crucial step towards power delivery industry adoption of EPRI's APD approach. An early decision point in the implementation of the approach focuses on determining to what extent existing data sources should be tapped to supplement expert knowledge. Hence, a project team of experts needs to evaluate data sources, such as those in the appendix of this report, to determine if they should be used in conjunction with the PMBD equipment models. The possibility of minimizing costs for evaluating such statistical data and relying more heavily on industry expertise embodied in the PMBD method is a viable alternative that EPRI will explore. The need for various types of asset management applications will determine the priority of the power delivery equipment initially modeled with the PMBD method. Asset management applications include repair/replace decisions in aging assets, maintenance program planning, inspection program planning, and evaluation of new technologies for incorporation into the power grid. In addition to defining software requirements for the APD and developing the needed software, EPRI will formulate guidelines to facilitate data collection using existing utility enterprise asset management systems. EPRI will then use the data gathered in this manner to further validate and enhance the PMBD models.

EPRI Perspective

The PMBD method has been in ongoing development in EPRI's Nuclear Power Sector since 1996, and has become a widely used tool and information resource in the nuclear power industry. In 2004, the PMBD method was applied to wood poles and underground cables, demonstrating its applicability to some of the more challenging power delivery equipment. Because use of the PMBD method creates equipment models, instead of the more traditional method of relying on statistical interpretation of event data, the APD approach allows asset managers in the power delivery industry to look forward – evaluating possible future scenarios in an effort to recommend the most reliable and economical course of action. This approach complements related past and current EPRI and industry efforts, including the Industry Wide Database, the Trans Grid Reliability Metrics Project, and numerous individual equipment studies conducted by various parties, such as the representative EPRI studies summarized in the appendix to this report. Related EPRI power delivery asset management products include reports 1008550, 1008552, 1011365, and 1008565. The APD approach offers utilities the advantages of the PMBD method coupled with the ability to better collect and enhance industry event data, which in turn will increase the value of other EPRI and industry data collection and evaluation efforts.

Keywords

Asset Management
Asset Manager
Maintenance Program
Root Cause Analysis
Performance Monitoring
Risk Management
PM Basis Database
Reliability
Power Delivery

ABSTRACT

Complexities and limitations of existing reliability data inhibit efficient asset management activities in the power delivery industry today. This report identifies and documents an approach that effectively addresses these reliability data limitations. The report briefly describes the relationship between this approach and other EPRI program efforts involving reliability data in the power delivery industry, and then identifies/prioritizes the next steps needed to bring about EPRI's Asset Performance Database (APD) approach. The report concludes that EPRI's PM Basis Database (PMBD) method – in ongoing development in EPRI's Nuclear Power Sector since 1996 – can play a key role in addressing asset management needs. Many of the equipment types already analyzed with the PMBD method are contained in power delivery systems (e.g., relays, breakers, transformers, etc.). Because use of the PMBD method creates equipment models, instead of the more traditional method of relying on statistical interpretation of event data, the APD approach provides component failure rate information that is more useful for asset management decisions. The APD approach provides asset managers in the power delivery industry the capability to estimate failure rate changes and therefore evaluate alternatives and recommend the most reliable and economical course of action.

An early decision point in the implementation of the APD approach focuses on determining to what extent existing data sources should be tapped to supplement expert knowledge. Hence, a project team of experts needs to evaluate data sources, such as those in this report's appendix, to determine if they should be used in the APD approach together with the PMBD equipment models. The need to move forward on various types of asset management applications will then drive the priority of the power delivery equipment to be modeled with the PMDB method. These applications include repair/replace decisions in aging assets, maintenance program planning, inspection program planning, and evaluation of new technologies for incorporation into the power grid. In addition to defining software requirements for the APD and developing the needed software, EPRI will formulate data collection guidelines to facilitate data collection using existing utility enterprise asset management systems. EPRI will then use the data gathered in this manner in a feedback loop to further validate and enhance the PMBD models.

ACKNOWLEDGMENTS

The EPRI project manager would like to acknowledge the contributions of the following individuals and organizations:

Nikki Delse of EPRI Solutions, Inc. who performed the survey of existing EPRI reliability databases.

David Worledge of Asset Performance Technologies, Inc., the prime source of material for Sections 2 and 3 and the creative force behind the failure data models upon which this proposed approach is based.

George Sliter of EPRI, the project manager for David Worledge's failure database work, which includes development of a similar database in the Nuclear Power Sector and who has consistently supported cross-cutting applications of EPRI technology such as this one.

Jeremy Bloom of EPRI, who immediately understood the value and applicability of the PM Basis in Power Delivery and who has also consistently supported cross-cutting applications of EPRI technology.

Steve Hoffman, Hoffman Marketing Communications, Inc. for his excellent support in report production.

CONTENTS

1 INTRODUCTION 1-1
Need for Improved Methods 1-1
Applications of Operating Event Data 1-1
Overview of Recommended Approach 1-1
Purpose and Organization of This Report 1-3

2 PM BASIS FAILURE RATE METHODOLOGY 2-1
Overview 2-1
Data Structure 2-1
Simplifying Assumptions Inherent in PMBD 2-3
Time Characteristics of Failure Mechanisms 2-5
Strength of Degradation Mechanisms 2-6
Raw Strength 2-7
Service Stressors 2-7
PM Task Attenuation of Failure Rate 2-8
The Effectiveness of a Single PM Task 2-9
Common Cause Effects of Multiple Tasks 2-11

3 PMBD VALIDATION 3-1

4 NEXT STEPS 4-1

A SURVEY OF EXISTING RELIABILITY DATABASES A-1
List of Reliability Databases A-1
EPRI 1002133: Asset Performance Database – Industry Database Design for Cables and Joints. December 2003. .... A-3
EPRI 1000424: Reliability of Electric Utility Distribution Systems: EPRI White Paper. October 2000. .... A-4
EPRI 1001873: A Review of the Reliability of Electric Distribution System Components: EPRI White Paper. December 2001. .... A-4

EPRI 1001704: Estimating Reliability of Critical Distribution System Components. January 2003. .... A-5

EPRI 1008459: Distribution Reliability Indices Tracking – Within the United States. May 2003. .... A-7

EPRI 1009633: Nuclear Asset Management Database – Phase 2: Prototype LAMDA (Long-term Asset Management Database). December 2004........ A-8

EPRI 1003188: Assessment of Component Reliability Databases for Turbo-XN. November 2001........ A-8

EPRI 1002128: Transmission System Reliability Performance Metrics Requirements. December 2003........ A-9

EPRI 1001971: Grid Equipment Reliability Study. December 2001. .... A-9

EPRI 1001827: Grid Equipment Reliability: Functional Requirements. December 2002. .... A-11

EPRI 1007281: Analysis of Extremely Reliable Power Delivery Systems – A Proposal for Development and Application of Security, Quality, Reliability, and Availability (SQRA) Modeling for Optimizing Power System Configurations for the Digital Economy. April 2002. .... A-12

EPRI 1001691: Improved Reliability of Switched Capacitor Banks and Capacitor Technology. December 2002. .... A-15

EPRI 1006952: Reliability Assessment of North American Steam Turbines. April 2002. .... A-16

EPRI 1004896: ERD Version 2.81.0016: Equipment Maintenance and Reliability Database Software. December 2003. .... A-17

EPRI 1004863: Component Failure Database, Version 2.0. December 2003. .... A-17

EPRI NP-7410: Circuit Breaker Maintenance – Volume 1: Low-Voltage Circuit Breakers, Part 3: Westinghouse DB Models. December 1992. .... A-18

EPRI 1002954: Guide for Predicting Long-Term Reliability of Nuclear Power Plant Systems, Structures and Components. December 2002. .... A-19

EPRI 1007422: Life Cycle Management Planning Sourcebooks – Volume 4: Large Power Transformers. March 2003........ A-20

EPRI 1007426: Life Cycle Management Planning Sourcebooks – Volume 7: Low Voltage Electrical Distribution Systems. February 2003. .... A-21

EPRI 1002637: TRELSS Application Manual – For Cascading Failure, Reliability, and Deterministic Analysis. October 2003. .... A-22

LIST OF FIGURES

Figure 1-1 Information Flow Using PM Basis Database and Asset Performance Database 1-3
Figure 2-1 EPRI PM Basis Database: Equipment Model Example 2-2
Figure 2-2 Degree of Degradation and Failure Rate Versus Time (lower curve is called the “failure time distribution) 2-4
Figure 2-3 Effect of a PM Task on the Failure Rate from a Single Failure Mechanism (dotted line shows failure time distribution without PM; solid line shows this distribution with PM) 2-4
Figure 2-4 Outline of the Calculation of Failure Rate using the PMBD Method 2-8
Figure 2-5 More Detail on Failure Rate Calculation Using the PMBD Method 2-10
Figure 3-1 Validation of the PM Basis Database, Based on a Comparison with EIReDA Data in the Nuclear Power Industry 3-2

1
INTRODUCTION

Need for Improved Methods

Much of the data collected today that asset managers need is difficult to use. Data is often collected in forms that are not electronic. And the data that is available electronically is often stored in text or narrative forms, which are difficult to evaluate. While some Enterprise Asset Management systems provide the means of collecting data more efficiently, the current implementations of these systems often suffer from lack of anticipation of asset managers' needs. These needs include easy access to asset performance data such as reliability estimates, return to service times, equipment health, and cost information.

The result is that analyzing existing data to determine component failure rates, for example, can be a costly proposition. Moreover, the data are limited to situations that have occurred in the past. For example, data exists only on the impact of maintenance programs that have been practiced in the past. This data does not enable asset managers to predict the impact on failure rates if the maintenance program is changed in the future. Similarly, the data does not allow asset managers to evaluate the potential value of retrofitting redesigned equipment or equipment employing new technologies. In summary, using past data only allows asset managers to look back, when they need to look forward.

Applications of Operating Event Data

Asset managers need data of this type for a range of applications. For example, operations, maintenance, and engineering applications include the following:

- Root cause analysis to improve human performance, and improve equipment design, operation, and maintenance
- Performance monitoring

Asset and risk management applications include the following:

- Repair/replace/redesign decisions on equipment in the short term and long term
- Configuration risk management

Overview of Recommended Approach

Based on the need for improved methods for the applications outlined above upon which EPRI could base the Asset Performance Database (APD), EPRI conducted a review of existing methods. This review quickly identified the PM Basis Database (PMBD) approach used in the nuclear power industry as a prime candidate to act as the basis for methods of calculating asset performance data. Further investigation confirmed that this approach is highly suitable for the needed task, and that in fact, many of the equipment types used in the PMBD approach are power delivery equipment (e.g., substation equipment at power plant sites).

The PMBD is based on a modeling approach that is initially driven by the input of expert knowledge, but then is amenable to refinement based on the input of collected event data. Because use of the PMBD is fundamentally a modeling approach, it allows asset managers to look forward – evaluating possible future scenarios in an effort to recommend the most reliable and economic course of action. Its initial reliance on the knowledge of maintenance, operations, and engineering personnel draws on the expertise and career-long experience of these power industry professionals.

EPRI's review concluded that the PMBD can be used in conjunction with the following complementary past and current EPRI and industry efforts to form an Asset Performance Database approach:

- The Industry Wide Database (IDB) is a database of individual events collected for participating utilities using developing industry standards.
- The Trans Grid Reliability Metrics Project (TGRMP, now under development) produces a set of transmission reliability metrics (that include both planned and forced outages).
- Various parties have conducted numerous individual equipment studies. Examples of these, which are summarized in Appendix A, used event data without the benefit of the IDB.

Figure 1-1 shows how these complementary efforts and the PMBD can work together in an approach that yields predicted failure rates for asset management decisions. As shown in the figure, the IDB, using event data, can be used to produce equipment studies. Forced outage data from the IDB can be used in the TGRMP to obtain reliability metrics. Further, experts draw upon their experience, knowledge of equipment, and event data from the IDB to update and maintain the PMBD models. In an "Asset Performance Database" approach, asset managers then use these PMBD models to calculate component failure rates and aid asset decision making. (The PMBD also aids maintenance program development – its original application.)

In addition to enabling prediction of component failure rates, the PMBD forms the basis for development of event data collection guidelines. Event data can then be gathered and incorporated into the IDB according to the procedures in these guidelines. In a feedback loop, this data is then used to validate the PMBD models and to improve and update them on an ongoing basis. Using the defined data collection procedures dramatically reduces data related costs and ensures that data is collected in a manner that supports asset manager tasks.

The data studies summarized in Appendix A can be evaluated for inclusion as input to the expert analysis for creating the PMDS or as sources for validation of the reliability estimates produced by the PMDB. While not analyzed as part of this effort, sources of applicable industry event data could be loaded into the IDB.

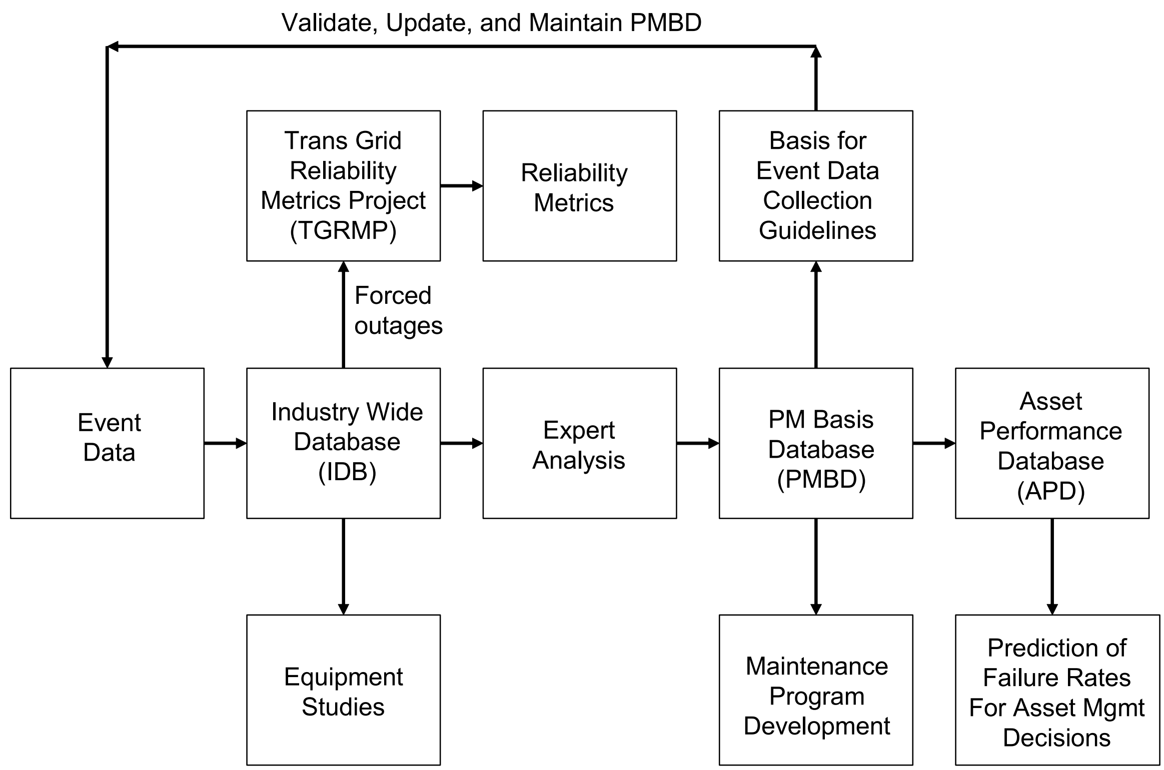


Figure 1-1
Information Flow Using PM Basis Database and Asset Performance Database

Purpose and Organization of This Report

The purpose of this report is to document an Asset Performance Database approach that is based on the PM Basis Database used in the nuclear power industry, to describe an overall methodology for applying this approach in the power delivery industry, and to identify/prioritize the next steps needed to achieve this goal. Section 2 describes the PM Basis Database approach. Section 3 summarizes how the PMBD was validated using operating experience data. Section 4 describes the next steps needed to implement the Asset Performance Database approach in the power delivery industry. Appendix A includes various data sources that can be considered for inclusion in this overall process.

2
PM BASIS FAILURE RATE METHODOLOGY

Overview

The Preventive Maintenance Basis Database (PMBD) has been in ongoing development in EPRI's Nuclear Power Division since 1996, and has become a widely used tool and information resource in the nuclear power industry. Over time, small groups of subject matter experts drawn from operating nuclear power plants and vendors have developed preventive maintenance (PM) tasks and task intervals. The PMBD was created as an information resource to supply recommendations on PM based on this disparate set of knowledge and experience.

Recently, these subject matter experts have included representatives of power delivery and fossil generation business sectors. The "nuclear only" database has recently expanded rapidly from approximately 80 major components to an "enterprise" database of more than 120 components. Additional components will be added to the database in 2005 and beyond.

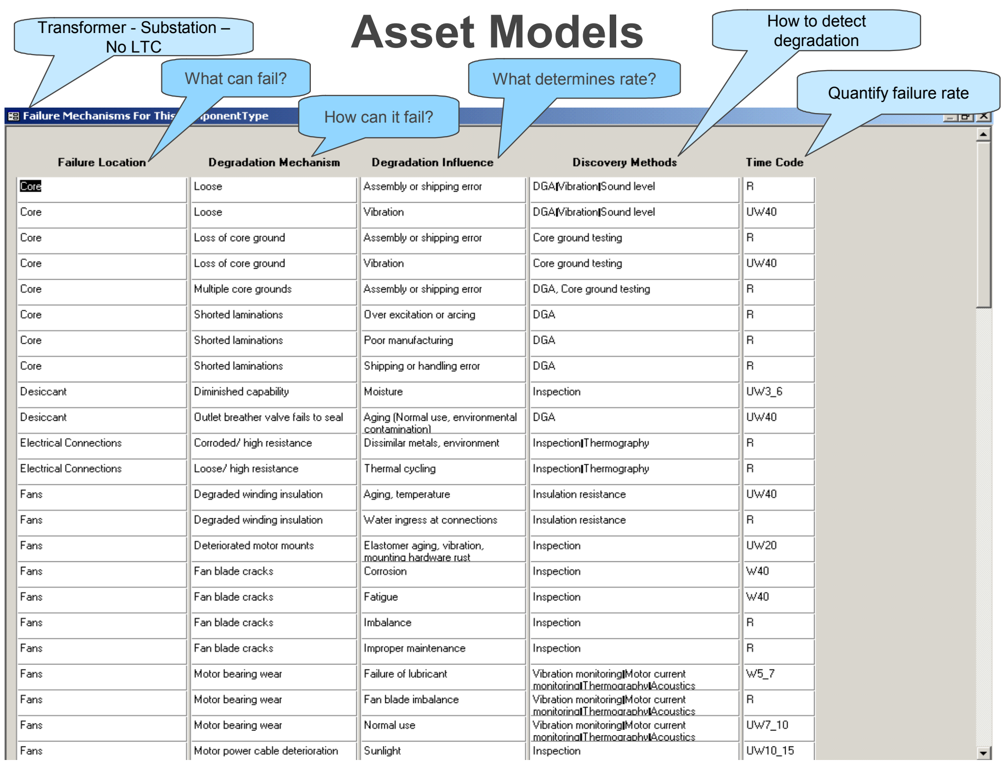
For each major component type, the PMBD provides a detailed description of failure mechanisms, a recommended program of PM tasks, a synopsis of the task content and intervals, and the reasons why these choices are technically valid in a variety of circumstances. Various industry bodies have conducted ongoing reviews and updates of the data in the PMBD. As a result, the PMBD is now approaching the status of a consensus repository of industry PM experience and expert judgment.

Over the same period, the PMBD's capabilities as an analytic decision tool have been greatly enhanced. These improvements have focused continually on answering the question "What is the quantitative effect of PM on equipment failure rates?" No other existing maintenance or reliability application provides the answer to this question. PM practices in all industries have relied primarily on expert judgment based on experience to match the expenditure of PM resources to the required reliability. The methodology described in this section enhances expert judgment with analysis.

Data Structure

In the PM Basis Database (PMBD), each component type is subdivided into a list of *Failure Locations* (e.g., core, desiccant, electrical connections, fans, etc.), which are basically its subcomponent parts (see Figure 2-1). Each of these is assigned *Degradation Mechanisms* (e.g., loose condition, loss of core ground, multiple core grounds, etc.). The latter are the processes by which the subcomponents degrade with use and the passage of time. Each degradation mechanism is further described by one or more *Degradation Influences* (e.g., assembly or shipping error, vibration, over-excitation or arcing, etc.). These are the stressors that initiate the degradation process and affect how rapidly it develops.

Figure 2-1 also lists corresponding *Discovery Methods* for each degradation influence. These methods are ways to detect the degradation (e.g., dissolved gas analysis, vibration analysis, core ground testing, thermography, etc.).



<table>
<tr><th>Failure Location</th><th>Degradation Mechanism</th><th>Degradation Influence</th><th>Discovery Methods</th><th>Time Code</th></tr>
<tr><td>Core</td><td>Loose</td><td>Assembly or shipping error</td><td>DGA|Vibration|Sound level</td><td>R</td></tr>
<tr><td>Core</td><td>Loose</td><td>Vibration</td><td>DGA|Vibration|Sound level</td><td>UW40</td></tr>
<tr><td>Core</td><td>Loss of core ground</td><td>Assembly or shipping error</td><td>Core ground testing</td><td>R</td></tr>
<tr><td>Core</td><td>Loss of core ground</td><td>Vibration</td><td>Core ground testing</td><td>UW40</td></tr>
<tr><td>Core</td><td>Multiple core grounds</td><td>Assembly or shipping error</td><td>DGA, Core ground testing</td><td>R</td></tr>
<tr><td>Core</td><td>Shorted laminations</td><td>Over excitation or arcing</td><td>DGA</td><td>R</td></tr>
<tr><td>Core</td><td>Shorted laminations</td><td>Poor manufacturing</td><td>DGA</td><td>R</td></tr>
<tr><td>Core</td><td>Shorted laminations</td><td>Shipping or handling error</td><td>DGA</td><td>R</td></tr>
<tr><td>Desiccant</td><td>Diminished capability</td><td>Moisture</td><td>Inspection</td><td>UW3_6</td></tr>
<tr><td>Desiccant</td><td>Outlet breather valve fails to seal</td><td>Aging (Normal use, environmental contamination)</td><td>DGA</td><td>UW40</td></tr>
<tr><td>Electrical Connections</td><td>Corroded/ high resistance</td><td>Dissimilar metals, environment</td><td>Inspection|Thermography</td><td>R</td></tr>
<tr><td>Electrical Connections</td><td>Loose/ high resistance</td><td>Thermal cycling</td><td>Inspection|Thermography</td><td>R</td></tr>
<tr><td>Fans</td><td>Degraded winding insulation</td><td>Aging, temperature</td><td>Insulation resistance</td><td>UW40</td></tr>
<tr><td>Fans</td><td>Degraded winding insulation</td><td>Water ingress at connections</td><td>Insulation resistance</td><td>R</td></tr>
<tr><td>Fans</td><td>Deteriorated motor mounts</td><td>Elastomer aging, vibration, mounting hardware rust</td><td>Inspection</td><td>UW20</td></tr>
<tr><td>Fans</td><td>Fan blade cracks</td><td>Corrosion</td><td>Inspection</td><td>W40</td></tr>
<tr><td>Fans</td><td>Fan blade cracks</td><td>Fatigue</td><td>Inspection</td><td>W40</td></tr>
<tr><td>Fans</td><td>Fan blade cracks</td><td>Imbalance</td><td>Inspection</td><td>R</td></tr>
<tr><td>Fans</td><td>Fan blade cracks</td><td>Improper maintenance</td><td>Inspection</td><td>R</td></tr>
<tr><td>Fans</td><td>Motor bearing wear</td><td>Failure of lubricant</td><td>Vibration monitoring|Motor current monitoring|Thermography|Acoustics</td><td>W5_7</td></tr>
<tr><td>Fans</td><td>Motor bearing wear</td><td>Fan blade imbalance</td><td>Vibration monitoring|Motor current monitoring|Thermography|Acoustics</td><td>R</td></tr>
<tr><td>Fans</td><td>Motor bearing wear</td><td>Normal use</td><td>Vibration monitoring|Motor current monitoring|Thermography|Acoustics</td><td>UW7_10</td></tr>
<tr><td>Fans</td><td>Motor power cable deterioration</td><td>Sunlight</td><td>Inspection</td><td>UW10_15</td></tr>
</table>

Figure 2-1
EPRI PM Basis Database: Equipment Model Example

The terms failure location, degradation mechanism, and degradation influence are approximately equivalent to the terms subcomponent, proximate cause, and root cause, respectively. A unique combination of values for these data fields forms one row or record in the component data table. This unique combination can be referred to informally as the failure cause or failure mechanism. All other information specific to that unique combination (e.g., discovery methods) are contained in the same row of the table.

Note that a failure location may have multiple degradation mechanisms. For example, the core may suffer from a loose condition, loss of core ground, multiple core grounds, etc. Similarly, a degradation mechanism may have multiple degradation influences. For example, the loose core condition may be influenced by an assembly or shipping error or by vibration.

These failure mechanisms may not always represent complete failure of the component functions. They more accurately correspond to the occurrence of clearly degraded states to which a maintenance professional would not wish to subject critical equipment. An estimate of the occurrence rate of these states may thus overestimate the true failure rate of the equipment.

The data structure shown in Figure 2-1 lends itself equally well to the description of complex active components and to passive components[1]. Proof of this assertion lies in the fact that the same approach has already been used with equal success for a broad range of components, including heat exchangers, feedwater heaters, DC power supplies, battery charger and inverters, 18 types of wooden utility poles, and ten types of underground power cables.

Performing a theoretically sound calculation of failure rate for components like these is not feasible because little of the required detailed information is available. This information includes not only the above specification of failure mechanisms, but also a detailed knowledge of the statistical failure times for each mechanism as a function of duty cycle and service stressors, as well as a detailed schedule of the PM activities and data on the effectiveness of each activity to mitigate and/or monitor each failure mechanism. Consequently, to estimate failure rates, the PMBD makes some important simplifying assumptions about the main influences on the failure rate.

Simplifying Assumptions Inherent in PMBD

In traditional life data analysis (i.e., Weibull analysis), it is not possible to determine the failure time distributions when more than a very small number of failure mechanisms are contributing, because many parameter sets can reproduce the same global outcome. When the component global failure rate is composed of possibly one hundred such contributions and the time origin of each distribution is randomized by many effects, the smearing is so complete that it is hard to maintain that the detailed shape of any individual failure mechanism is important. In addition, the randomizing of the time origin, due to "restarting the clock" at the occurrence of each PM task, leads to the conclusion that every failure mechanism may be treated as giving a constant failure rate.

Hence, the key simplifying assumption in the PMBD method is that the detailed shape of the time dependence of the failure rate mechanism is unimportant. Instead of focusing on the shape of this function, the PMBD method focuses on whether a failure mechanism exists at all and whether the mechanism is related to wear or is a random occurrence.

With regard to wear, the most important parameter of a wearout pattern of failures is the earliest occurrence (i.e., minimum life) at which failures are observed in a population of items (see top of Figure 2-2). Represented by the dotted line in Figure 2-2, the minimum life is the minimum time needed for the degradation process to advance to the threshold of failure in the "weakest" of a population of items. Maintenance professionals usually are able to estimate this value from their direct experience, avoiding the need for statistical analysis.

---

[1] While there are a variety of definitions available for a passive component, the most common attributes are: functioning does not depend on external input, no moving parts, very high reliability based on irreversible action or change (sometimes) and also (specific to electrical) components without gain or current-switching capability. Examples include resisters, cables, conduit, wood poles and structures.

The next most important wearout parameter is the period over which failures continue to be observed after the failure threshold has been reached (see the lower portion of Figure 2-2). This is roughly the width of the failure time distribution (see Figure 2-3). For simplicity, the width of the failure time distribution can be assumed to be roughly proportional to the minimum life. This assumption can be relaxed if specific examples provide additional information. Clearly there are cases in which the width of the failure time distribution is much less than the minimum life and does not follow this assumption. These cases most often apply to consumer items for which the lifetime of extremely large numbers of components has been studied exhaustively and driven to a commercially optimal value. Examples are automobile batteries and light bulbs.

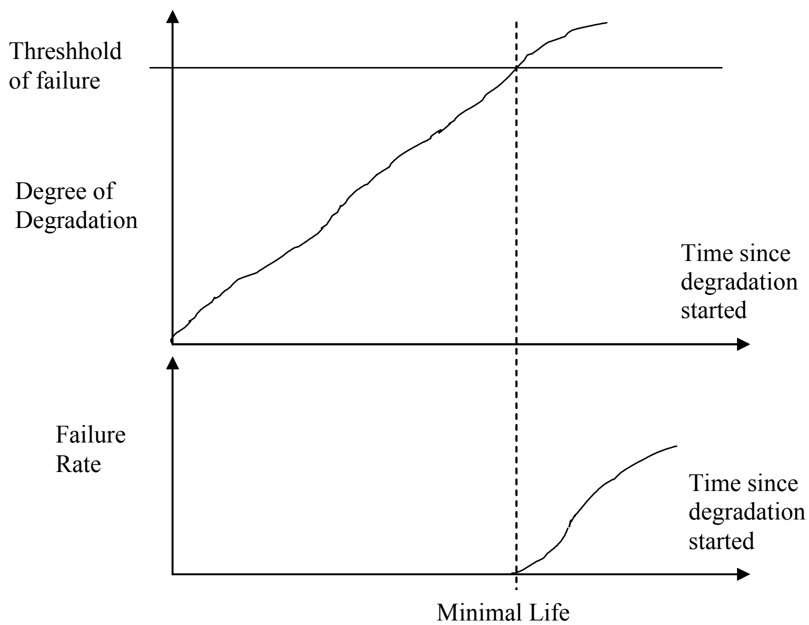


Figure 2-2
Degree of Degradation and Failure Rate Versus Time (lower curve is called the "failure time distribution)

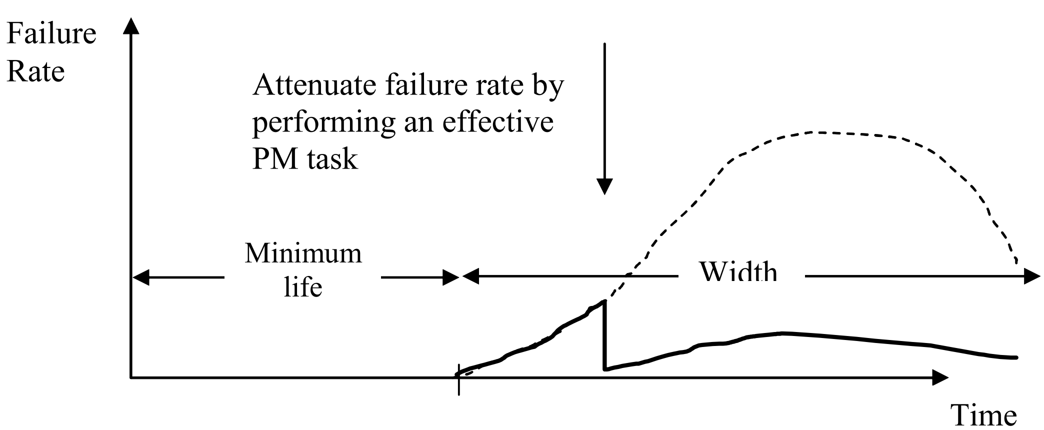


Figure 2-3
Effect of a PM Task on the Failure Rate from a Single Failure Mechanism (dotted line shows failure time distribution without PM; solid line shows this distribution with PM)

Subject matter experts estimate the uncertainties in the minimum life. These uncertainties account for the following:

- Effects of variations in nominal stressors (i.e.. those that apply in nominally unstressed circumstances)
- Variation in design margin built into the component
- Imperfect restoration of the component to a good-as-new condition after repair or PM activity.

In critical applications in any industry where significant resources are devoted to preventive maintenance, only the leading portions of the failure time distributions are actually experienced. The reason is that as soon as the first failures become part of industry operating experience, PM tasks are implemented to prevent the majority of failures that would otherwise occur. Figure 2-3 illustrates this by showing the failure time distribution without PM (dotted line) and the failure time distribution with PM (solid line).

The main premise of the PMBD approach for deducing failure rates is that it is more important to represent the gross effects of duty cycle and many other service stressors, and the approximate degree to which specific PM tasks can be expected to address specific failure mechanisms, than to represent these effects in theoretical detail. The general strategy is to model the known dominant effects in a simple way, so that the PMBD contains at least a basic representation of all that is known about the influence of PM tasks on the failure rate of equipment.

There is a good reason why this strategy can be expected to be successful. Without the benefit of sophisticated information and decision tools such as the PMBD, PM program personnel have been able to construct fairly robust and effective PM programs over time with only a most basic consideration of these gross effects. Adding the power of a computerized database can be expected to improve on these basic methods. The PMBD can provide the following:

- Convenient access to industry recommendations
- More comprehensive accounting for the above gross effects
- Fast, standardized estimation process that will allow a technical basis to be quickly established for a wider range of maintenance decisions.

Time Characteristics of Failure Mechanisms

Once the failure mechanism for a subcomponent has been roughly characterized as described above, the next crucial piece of information that must be specified is the *Time Code* (see Figure 2-1). Each failure mechanism (i.e., row in the component table) is described as random mechanism or a wearout mechanism.

A random failure mechanism is one for which the probability of occurring in a given time period is independent of when that period occurs in the life of the component. For example, the probability of failure at the beginning of service life, after one year in service, and near the end of service life, are identical. Random mechanisms are designated as “R.”

A wearout failure mechanism (designated as "W") behaves much differently than a random failure mechanism. For a wearout failure mechanism, the probability of causing a failure is zero until a minimum period of usages has expired (the minimum life in Figure 2-2). During the period, the level of degradation that the component experiences is increasing, but the component has not yet reached the threshold beyond which the component may fail. After this period, failures occur over a statistical distribution of failure times.

A wearout mechanism is assigned a time code such as W5, which means that failures can be expected after a minimum life of 5 years. A time code of W5_8 means that the minimum life is uncertain and cannot be specified any more precisely than the range of 5-8 years.

Wearout failure mechanisms are further subdivided into those designated simply using a "W" as above, and those described by a "UW" code. The latter subgroup is reserved for failure mechanisms that every unit of the particular subcomponent type universally experiences. When any unit of that subcomponent type is put into service, degradation begins, and failure by these mechanisms cannot be arrested. The UW code usually refers to cases of aging or wearout due to normal use of the equipment. The "U" part of the UW code can also be thought of as the ubiquity of the cause to all units, or the unconditional nature of the cause.

In contrast, the single letter "W" code is applied to wearout mechanisms that are conditional on some other event to initiate them. These are surprisingly common. One example is environmental dust contamination of 6.6-kV switchgear contacts. If the contamination is most likely an episodic exposure to a source such as nearby construction, the code becomes "W." The reason is that under normal circumstances, the exposure would not occur at all. Degradation and failure requires the random occurrence of such exposure to begin the process.

In some cases, otherwise similar failure mechanisms may differ markedly in time code because of differences in the "quality" of the subcomponent. In these cases, the subcomponent may be assigned more than one row of this failure mechanism. This approach also applies when the failure mechanism may not exist for a design variant; one row can be assigned to the standard design, and a second row can be assigned in the database to the design variant.

The three types of time codes thus provide a simple means of describing a wide range of failure time behavior. Of course, the appropriate designation for a given case may not be obvious. This source of uncertainty is not quantified in the PMBD approach.

Strength of Degradation Mechanisms

The PMBD model intentionally does not track the detailed relationship between the initiation of a wearout mechanism and the evolution of time. Nor does the model track the absolute time at which any PM task is performed. The reason is that this information is not typically available to the user. To perform a calculation of this kind would require the piecewise solution of reliability integral equations, in concert with a planned schedule of PM tasks.

As an alternative to this method, the PMBD method roughly estimates a constant failure rate contribution from each wearout process. The method also assumes that each random mechanism also contributes a small constant failure rate, which is assumed to be the same for all random mechanisms.

Raw Strength

The PMBD uses the general term of "strength" to characterize the potential of a degradation mechanism to reduce the reliability of a subcomponent. A strong mechanism not attenuated by PM tasks has substantial impact on the failure rate. In this usage, "strength" is measured by the frequency with which the mechanism produces a severely degraded condition. The term represents the severity of the challenge to any PM task intended to mitigate it. If the applied PM task does not adequately reduce the frequency of the severely degraded condition, then the strength of the failure mechanism automatically becomes the failure rate from the failure mechanism. Degradation mechanisms with large values of strength have a potentially strong effect on the failure rate, whereas those that are weak do not. An example of a strong degradation mechanism is a filter that will shut down a component when it becomes sufficiently clogged, perhaps after a six-month period. This is a strong challenge to the PM program because the filter must be cleaned or changed frequently. The failure rate from this single strong mechanism would be close to two per year if no PM was performed. In contrast, a random mechanism caused by a manufacturing defect may have a strength of only 0.0005 per year. This mechanism is "weak" because even if no PM is performed to attenuate it, this mechanism does not have a large impact on the failure rate.

The PMBD procedure examines each failure mechanism (i.e., row in the table) independently to calculate the strength of the mechanism and then to modify the strength according to applicable stressors. It is convenient to refer to the strength before it is modified by stressors as the "raw strength."

The method assumes that each random mechanism contributes a small constant failure rate, which is assumed to be the same for all random mechanisms. Hence, all mechanisms with a simple W time code have a strength equal to the random strength because these mechanisms require a random influence to trigger the wearout process. This means that the raw strength of these types of mechanisms is independent of their minimum life and the width of the failure rate distribution.

Service Stressors

The raw strength of each failure mechanism is subjected to modification by service stressors (see Figure 2-4). The potential influence of service stressors is identified by keywords that appear in the *Degradation Influence* field. Some failure mechanisms posies one or more of the keywords, while others do not. For example, keywords for duty cycle stressors include run time, runtime, cycle, normal wear, and start. Keywords for heat stressors include heat, hot, temp, and thermal.

When the user has indicated that a particular stressor group should be applied, a keyword search is conducted on the *Degradation Influence* field. For each mechanism (row in the table) where a keyword is found, a stressor correction is applied to the raw strength that has already been calculated. The general procedure when stressors act follows:

- For each unconditional wearout (UW) mechanism, the model decreases the minimum life, which increases the mechanism's strength.
- For each conditional wearout (W) mechanism, the model modifies the mechanism so that it behaves somewhat like unconditional wearouts, which can greatly enhance the mechanism's strength.
- For each random (R) mechanism, the model significantly increases the strength of the mechanism. (Unless random mechanisms are enhanced by this action of stressors, random mechanisms typically do not strongly impact the overall degradation rate.)

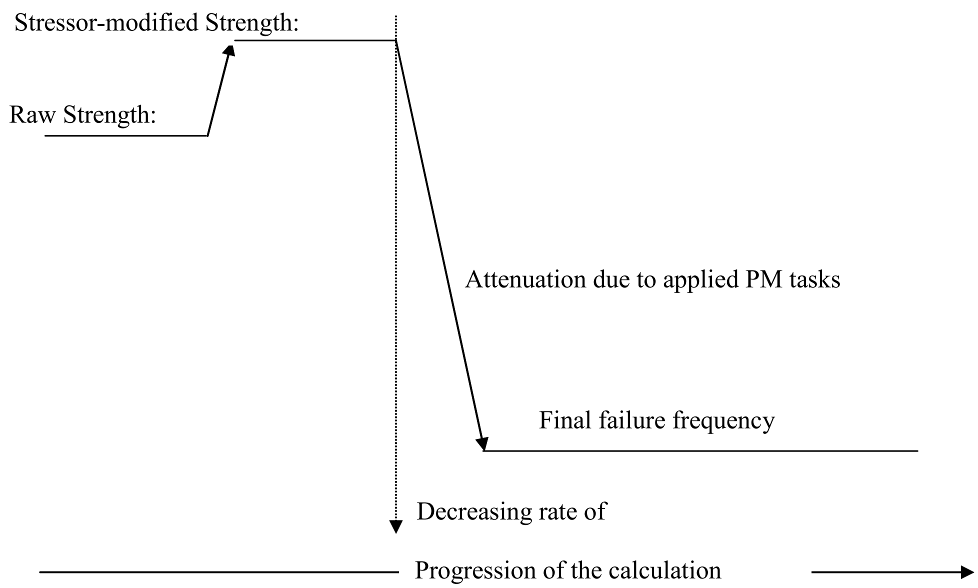


Figure 2-4
Outline of the Calculation of Failure Rate using the PMBD Method

Thus, the type of failure mechanism (i.e., W, UW, and R), its timing parameters (e.g., minimum life), and the applicable stressors influence the value of the strength of each failure mechanism. Because the strength represents the rate of occurrence of unmitigated degradation processes, it represents the challenge that the PM program must counter. The objective of PM tasks is to attenuate the strength of these challenges so that few of them become actual failures.

PM Task Attenuation of Failure Rate

Figure 2-4 shows that attenuation of failure rates due to applied PM tasks decreases the failure rate from the stressor-modified strength to the final failure frequency. This effect of a given maintenance activity could be referred to as "maintenance benefit." Experience with equipment long-term planning (LCM) has shown that the maintenance benefit is one of the main drivers (if not *the* driver) of planning evaluations and decision making. That is, many asset management decisions, e.g., when to replace equipment instead of repairing or refurbishing it, are often influenced significantly by just how cost effective various maintenance alternatives can be.

Each PM task is assigned an intrinsic effectiveness (IE) against each failure mechanism. IE represents the probability that if the task were to be performed when the degraded condition is sufficiently advanced; it would lead to appropriate action to mitigate the advancing degradation. By using this definition, an IE can be assigned as a function of task and failure mechanism that is independent of when the task is performed.

The Effectiveness of a Single PM Task

A task itself does not lead directly to identification of the offending mechanism, but it should set in motion actions that would have the effect of averting the impending in-service failure. The IE parameter summarizes what can be expected from the task under ideal performance conditions (i.e., the task in not performed too soon nor too late, and it has the maximum opportunity to detect the presence of the condition).

The IE parameter is part of the basic component data stored in the PMBD component tables and takes on only one of four values – high, medium, low, or null:

- A high value {“H”) indicates that the task is virtually certain (97 percent probability) to detect the degraded condition
- A medium value (“M”) indicates a moderate effectiveness (80 percent probability)
- A low value (“L”) indicates only an even chance (50 percent probability) of success.
- A null value (a blank data field) means that the PM task is not expected to address the failure mechanism at all.

Maintenance personnel easily identify with this H, M, and L categorization of maintenance effectiveness. Theoretically, the numerical values of the probabilities (i.e., 97 percent, 80 percent, etc.) could be parameters of the model, but so far have not been varied from these nominal values.

However, in reality, the actual overall effectiveness of a PM task is highly dependent on the time at which it is applied in relation to the minimum life. Even though the PMBD uses a time-smeared approach to the estimation of rate processes, which essentially randomizes all time origins in the problem, it is possible to be fairly specific about how the timing of the PM task influences its effectiveness. If the task is applied later in the service life, relative to the minimum life, for a wearout mechanism, it is likely to be less effective than if it was applied earlier in the service life.

Consequently, the PMBD model compares each “task interval” to the relevant time that the time code indicates. (The “task interval” is defined as the length of time between the in-service date of the subcomponent and the date that the PM task is performed.) The method then reduces the intrinsic effectiveness according to a predetermined set of rules. For random mechanisms, the PM task should be performed as early in the subcomponent’s life as possible, because the random mechanism that triggers the degradation can occur at any time. Hence, for these mechanisms, a task’s effectiveness is downgraded one step if the task interval is great then 3 months but less than or equal to 6 months; H becomes M, M becomes L, and L remains as L. IF a task interval is great than 6 months, all tasks are downgraded to low overall effectiveness: H is downgraded to L, M becomes L, and L remains as L.

For wearout mechanisms, the H, M, and L values of intrinsic task effectiveness are successively downgraded depending on the degree to which the task interval exceeds the minimum life. This makes sense because performing the maintenance task after the first unit of a population of a certain kind of subcomponent is expected to fail will be less effective than performing the task earlier in the subcomponent's life.

The resulting values of task effectiveness are known as the Overall Effectiveness (OE) and are used to attenuate the strength of each failure mechanism. For example, if a maintenance task is performed after minimum life, the stressor-modified strength would be increased, yielding a higher final failure frequency (see Figure 2-5).

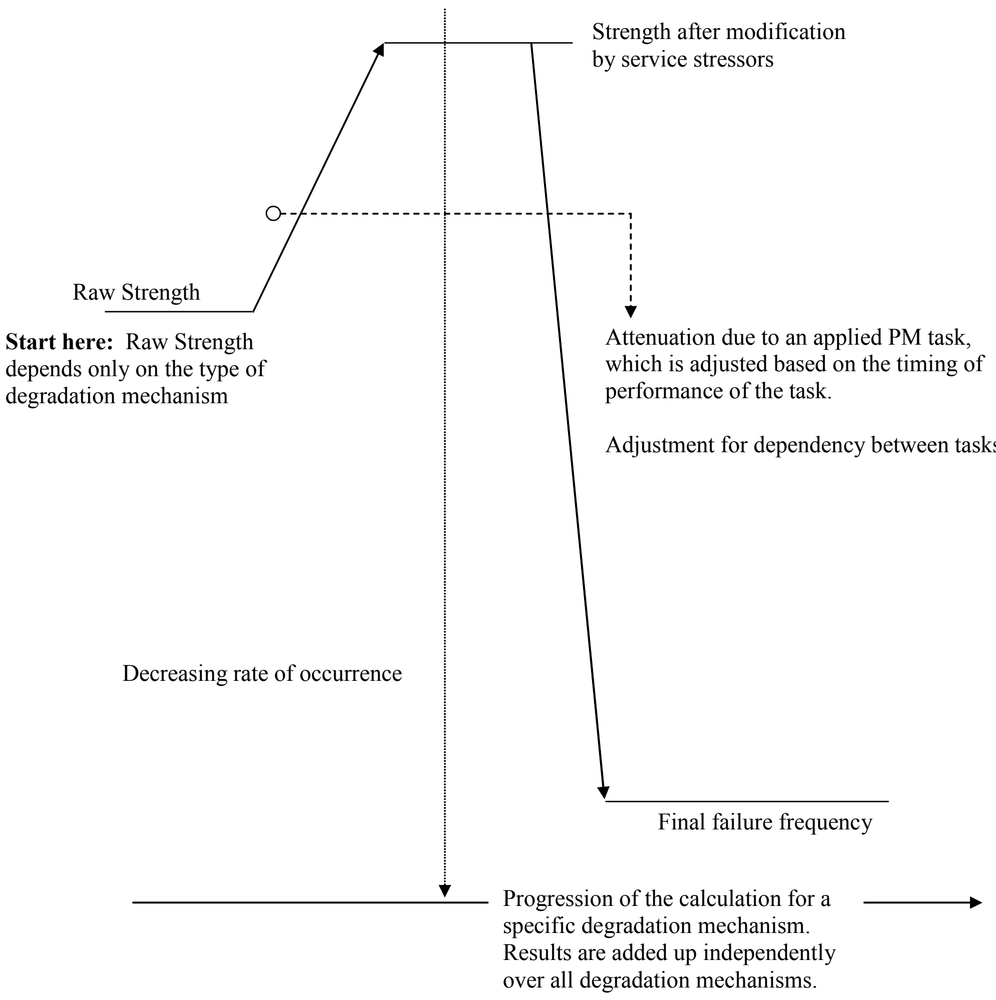


Figure 2-5
More Detail on Failure Rate Calculation Using the PMBD Method

Common Cause Effects of Multiple Tasks

When more than a single PM task addresses a degraded condition, the overall task effectiveness values determined for each task are combined. The combination recognizes that if one task fails to detect the condition, some characteristics of the condition itself, or of other circumstances, reduce the likelihood that the other tasks will detect it. In other words, the PMBD does not treat the PM task as independent variables. Common shortcomings in the quality of training or procedures can also introduce a common cause effect between tasks. The combined task effectiveness approach in the PMBD model also represents this effect.

The PMBD model calculates the probability that a sequence of n tasks fails to detect the condition. If all tasks were independent, and the overall effectiveness of each was OI_i, this probability would be:

$$\text{Probability of non-detection} = (1\text{-}OE_1) \times (1\text{-}OE_2) \times (1\text{-}OE_3) \times \ldots (1\text{-}OE_n)$$

Using the common-cause model, this expression is replaced by:

$$\text{Probability of non-detection} = (1\text{-}OE_1) \times (1\text{-}OE_2)^{1/2} \times (1\text{-}OE_3)^{1/3} \times \ldots (1\text{-}OE_n)^{1/n}$$

This model is a very simple way to create a parameter-free common cause effect between interacting variables. In the field of reliability, this model produces results that compare well with results of the common beta factor model for very effective tasks, but without the inconvenience of introducing an extra variable (the beta factor). Additionally, when the tasks are not very effective, the model reproduces the effect of a stronger common cause coupling – an increasing beta factor, ß(OE) – which almost cancels out the benefit of additional low effective tasks. This is a desirable effect. For example, with just two tasks in combination, each with the same value of OE, the ratio of the common cause attenuation to the attenuation of a single task is $(1\text{-}OE)^{-0.5}$. This means that two highly effective inspections have a combined attenuation that is 5.8 times that of a single inspection (instead of 33 times for independent tasks). But two medium effectiveness tasks are only 2.2 times better than a single task, and two low effectiveness tasks are only 1.4 times better than a single task. The common cause probability of non-detection is applied to the strength to evaluate the resulting failure rate (see Figure 2-5).

3
PMBD VALIDATION

In EPRI report 1009633, the project team conducted a comparison of PM Basis Database data and data from the European Industry Reliability Databank (EIReDA, 3rd edition published in 1998, Crete University Press), which contains data that is mainly derived from French nuclear power plants. Out of 31 comparisons ("data points") of PM Basis results with EIReDA data:

1. 13/31 = 32% are predicted to be within a factor of 2.
2. 19/31 = 61% are predicted to be within a factor of 3.
3. 27/31 = 87% are predicted to be within a factor of 4.
4. 30/31 = 97% are predicted to be within a factor of 5.

According to accepted industry practice, a range of a factor of 5 about the data mean values should contain the "true" (PM Basis) values at least 90 percent of the time. According to the above results, 97 percent of the EIReDA results actually do fall in this range. Less optimistically one might claim that 90 percent of the EIReDA results should fall within a factor of 10 of the PM Basis results, and 97 percent actually do. Indeed, it is almost true that 90 percent fall within the more narrow range of a factor of 4 – the above result shows that 87 percent fall in this range.

Consequently, the EPRI report concludes that the EIReDA values are entirely consistent with the PM Basis values, taken as the "true" values, if it is assumed that the applicable error factor on the EIReDA values is 5 or 10. The EIReDA values are almost consistent with the PM Basis values even if the error factor on the data is as low as 4. From this, the report concludes that the PM Basis results are indistinguishable from the true failure rates on the basis of 31 samples of EIReDA data, taken as generic data. Figure 3-1 plots the results of this data comparison for the 31 samples, showing the fairly close correlation across subcomponents.

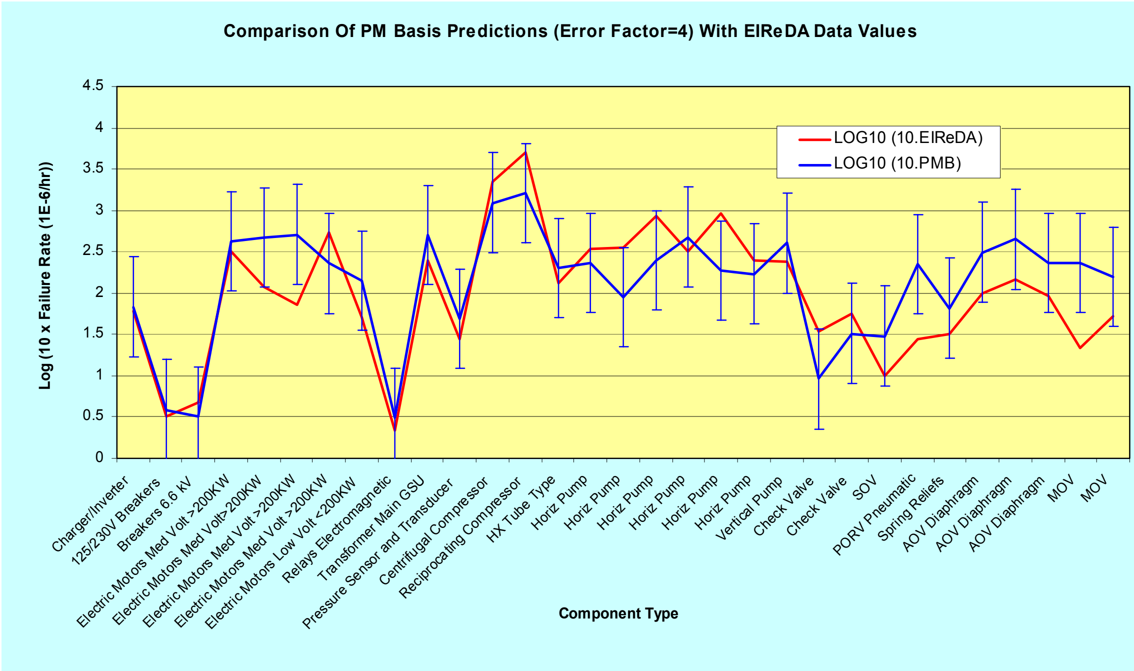


Figure 3-1
Validation of the PM Basis Database, Based on a Comparison with EIReDA Data in the Nuclear Power Industry

4 NEXT STEPS

This report documents the first crucial step towards power delivery industry adoption of the APD approach. Next steps will consist of the following:

- Task 1. Determine to what degree available sources of generic reliability data (e.g., EPRI sources in Appendix A and other industry data sources) should be compiled and evaluated for use in this approach
- Task 2. Prioritize list of power delivery components to model, based on need for data and planned applications
- Task 3. Conduct modeling of power delivery components in priority order, based on expert input
- Task 4. Define requirements for software to support the APD
- Task 5. Develop software to support use of the APD in asset management decision making
- Task 6. Develop data collection guidelines for this approach
- Task 7. Collect event data for high priority power delivery components, and use this data to further validate the PMBD models

An early decision point in the implementation of the approach is to determine to what extent existing data sources should be tapped to supplement expert knowledge. Hence, a project team of experts needs to evaluate data sources (task 1) like those in Appendix A and efficiently determine if they warrant qualification for use in the approach. The alternative of minimizing costs of evaluating these data and relying on industry expertise for modeling is a viable approach that the project team should explore.

The need to move forward on various types of asset management applications will drive prioritization of components to model, as well as actual modeling (task 2). These applications include the following types:

- Repair/replace decisions in aging assets
- Maintenance program planning
- Inspection planning (e.g., what to inspect, when to inspect, and how often to inspect)
- Evaluation of new technologies for incorporation into the power grid

A prioritized list of power delivery components is under development for the Aging Assets project in the Power Delivery Asset Management program. Some of the components on this list will be modeled in 2005. Wood poles and underground cables were modeled in 2004.

With regard to data collection guidelines (task 6), information standards such as the Common Information Model (CIM) will be used to facilitate data collection throughout the utility enterprise. The guidelines and standards will be designed for incorporation into work management, outage management, customer information, and process data systems. Data gathered in this manner will then be used to further validate the PMBD models (task 7). Also, it is important that we can begin now to develop data collection guidelines (Task 6) for certain power delivery components in the PMDB and add to those guidelines as modeling proceeds (Task 3).

A
SURVEY OF EXISTING RELIABILITY DATABASES

List of Reliability Databases

A list of the reliability data sources and databases summarized in this appendix follows.

The list represents a relatively comprehensive review of EPRI reports on reliability databases and a representative review of EPRI equipment studies that contain reliability information. The information in this Appendix reflects the statements of the original EPRI report; no attempt was made to separately "qualify" these data sources.

Reports on the Industry Wide Database (IDB) (EPRI 1002133) and the Transmission Grid Reliability Metrics Project (TGRMP) (EPRI 1002128) are included. Grid reliability studies that are precursors to TGRMP are also included. Reports representing a series of reliability and failure rate studies for transmission and distribution components are also included as is a comprehensive study on distribution reliability metrics and results (EPRI 1008459).

These reports are complemented by a series of equipment studies on various electrical equipment, some from studies in the Nuclear or Generation sector, e.g., circuit breakers and large power transformers, and some from Power Delivery sector studies, e.g., capacitor banks. Most of these studies do not directly report failure rates. More typically, they might report a percentage of failures due to particular contributing causes, maintenance practices or service conditions.

Each of these types of studies is applicable to the Asset Performance Database information flow illustrated in Figure 1-1. In some cases, the studies serve as the best available information for asset managers and equipment specialists while EPRI implements the approach described in this report.

EPRI 1002133: Asset Performance Database – Industry Database Design for Cables and Joints. December 2003. .... A-3

EPRI 1000424: Reliability of Electric Utility Distribution Systems: EPRI White Paper. October 2000. .... A-4

EPRI 1001873: A Review of the Reliability of Electric Distribution System Components: EPRI White Paper. December 2001. .... A-4

EPRI 1001704: Estimating Reliability of Critical Distribution System Components. January 2003. .... A-5

EPRI 1008459: Distribution Reliability Indices Tracking – Within the United States. May 2003. .... A-7

EPRI 1009633: Nuclear Asset Management Database – Phase 2: Prototype LAMDA (Long-term Asset Management Database). December 2004.. A-8

EPRI 1003188: Assessment of Component Reliability Databases for Turbo-XN. November 2001.. A-8

EPRI 1002128: Transmission System Reliability Performance Metrics Requirements. December 2003.. A-9

EPRI 1001971: Grid Equipment Reliability Study. December 2001................................. A-9

EPRI 1001827: Grid Equipment Reliability: Functional Requirements. December 2002. .... A-11

EPRI 1007281: Analysis of Extremely Reliable Power Delivery Systems – A Proposal for Development and Application of Security, Quality, Reliability, and Availability (SQRA) Modeling for Optimizing Power System Configurations for the Digital Economy. April 2002. .... A-12

EPRI 1007442: Reliability Assessment of the Coronado Generating Station. March 2003. .... A-14

EPRI 1001691: Improved Reliability of Switched Capacitor Banks and Capacitor Technology. December 2002. .... A-15

EPRI 1006952: Reliability Assessment of North American Steam Turbines. April 2002. .... A-16

EPRI 1004896: ERD Version 2.81.0016: Equipment Maintenance and Reliability Database Software. December 2003. .... A-17

EPRI 1004863: Component Failure Database, Version 2.0. December 2003. .... A-17

EPRI NP-7410: Circuit Breaker Maintenance – Volume 1: Low-Voltage Circuit Breakers, Part 3: Westinghouse DB Models. December 1992. .... A-18

EPRI 1002954: Guide for Predicting Long-Term Reliability of Nuclear Power Plant Systems, Structures and Components. December 2002. .... A-19

EPRI 1007422: Life Cycle Management Planning Sourcebooks – Volume 4: Large Power Transformers. March 2003... A-20

EPRI 1007426: Life Cycle Management Planning Sourcebooks – Volume 7: Low Voltage Electrical Distribution Systems. February 2003. .... A-21

EPRI 1002637: TRELSS Application Manual – For Cascading Failure, Reliability, and Deterministic Analysis. October 2003. .... A-22

EPRI 1002133: Asset Performance Database – Industry Database Design for Cables and Joints. December 2003.

Goal

- To provide a functioning industry database for cables, joints, and terminations for maintenance and failure analysis purposes, particularly maintenance and asset management optimization based on company and industry-wide equipment performance analysis

Results

The Common Information Model (CIM) approach encompasses an exhaustive definition of failure cause, root cause, failure modes, failure analyses, and other cable attributes relevant for maintenance optimization and asset management. The resulting asset performance database, subsequently changed to the Industry Wide Database (IDB) allows utilities to document and track all cable, joint, and termination failures and permits update of utility-specific cable failure information. The database also permits utilities to analyze failures using the powerful portals feature, where they can chart and trend failure count and rates by failure type, vintage, manufacturer, or any other criteria needed. Finally, the database facilitates the creation of instant reports with a click of a button. Industry-wide, this database is unmatched in its collection of failure data coupled with population maintenance, and operational data. The IDB's development basis in CIM and reliability centered maintenance (RCM) concepts in similarly unique, including for example, extension of standards and standardized naming conventions to cover maintenance and asset management data objects and attributes.

Intended Sector: Transmission

Relevant Components

Cables, joints, and terminations

Criteria

Quality of data: Fairly high. Component boundaries most likely well defined because of the use of CIM. Availability of the data should be able to be tracked back to specific plants. (Note: CIM is an abstract model that represents all the major objects in an electric utility enterprise typically involved with utility operation. By providing a standard way to represent power system resources as object classes and attributes, along with their relationship, the CIM facilitates the integration of Energy Management System (EMS) applications developed independently by different vendors, between entire EMS systems developed independently, or between an EMS system and other systems concerned with different aspects of power system operations, such as generation and distribution systems.)

EPRI 1000424: Reliability of Electric Utility Distribution Systems: EPRI White Paper. October 2000.

Goals

- To document what is known about reliability in distribution systems
- To determine whether tools exist to perform the required reliability analysis for planning distribution systems

Results

There is no generally available implementation or methodology that will permit distribution system planners to predict distribution system reliability. Not only is a usable methodology absent, but there is no general framework available for reliability-based decision making in the distribution system. It is not possible to answer such questions as

- How will an additional investment in the distribution system affect customer service reliability?
- How will a chance in maintenance policy affect customer service reliability?
- What is the optimal level of maintenance for the distribution system?
- What level of redundancy is appropriate for the distribution system?

New methodology is needed because the state of the art in practice does not address the problems distribution systems planners currently face.

Intended Sector: Distribution

Relevant Equipment

Total distribution systems

EPRI 1001873: A Review of the Reliability of Electric Distribution System Components: EPRI White Paper. December 2001.

Goals

- To document what is known about reliability of individual distribution system components as they age
- To determine whether sufficient information exists to perform the required reliability analysis of aging distribution systems

Results

A detailed literature survey, the Reliability Data Library, is described in this report. The Library is a tool intended to support further development of models and methodology. The Reliability Data Library can be used by utilities to locate component reliability data and information on other topics related to the reliability of aging components.

The literature review found extensive data available on the reliability of individual components. With cautious use, this data can provide the basis for system reliability analyses. However, reliability is greatly influenced by maintenance and environmental factors that are unique to the individual utilities. This report's key finding is that it is extremely important that individual utilities track their individual component reliability so that over time they can understand the unique reliabilities of their installed components. There is no single generally available dataset that distribution planners can use to answer all questions associated with reliability-based planning.

Intended Sector: Distribution

Relevant Components

Distribution system components, including bus bars, overhead conductor, underground cable, underground splices, elbows, capacitor banks, wooden poles, switches, circuit breakers, reclosers, fuses, substation transformers, pole-mounted transformers, pad-mounted transformers, submersible transformers, lightning arrestors and voltage regulators.

Criteria

Report states, "if data is the focus of the publication [from which the data is taken], the sample size and dates of data collection are provided, but little else. Data from sources where modeling is the primary topic and data the secondary topic are generally not well documented." Quality of data cannot really be confirmed without a lot of leg work, and data from sources where it was the secondary topic may not be able to be traced back to its origin. Data from this report is a combination of data sources.

Ranges of failure data in this report are said to be quite large, which the report attributes to unique conditions at the different plants.

EPRI 1001704: Estimating Reliability of Critical Distribution System Components. January 2003.

Goals

- To describe a methodology and practical tools for estimating failure rates and hazard or failure functions

- To describe four spreadsheets developed to assist in the prediction of failure rates – one spreadsheet is applicable to any type of distribution asset and the other three are specific to underground cable, distribution transformers, and power transformers

Results

The spreadsheets are useful tools for estimating failure rates. They are unique in both their detail and their approach to determining failure rates. No other failure rate source links detailed descriptions of equipment, environment, use, and test results with failure rates or provides the detail necessary to estimate relevant failure rates. No other tool formally considers uncertainty in failure-rate estimates, allows integration of such a wide variety of knowledge relevant to failure rates, or uses a consistent Bayesian approach to knowledge integration.

Due to lack of historical failure data, lack of data on test accuracy, lack of operating data, uncertainty with respect to future equipment use, and lack of field testing the spreadsheets predict wide confidence bands about failure rates. Additional research including expanding expert input, testing with utilities, expanding the equipment covered and standardizing failure data collection would be highly valuable.

A large compilation of references (201 articles) was created separately and is available to program funders.

Intended Sector: Distribution

Relevant Components

Underground cable, distribution transformers, and power transformers

Criteria

Some aspects of the data used to create the failure estimate spreadsheets are assumed. For example, the report states that if the key design parameters are not known, they are assumed to be typical of the vintage. Also, if environmental conditions are not known they are assumed to be typical.

Recent failure data or test data can be used to update the estimated failure rates. If recent failure data is used, probability distributions are estimated by the author. Gamma and normal distributions describe the failure rate and the failure rate increase, respectively. Test data is not necessarily as useful as actual failure data, because test interpretation is an art, tests have been used to pinpoint problems not to predict failure probability, and statistics on accuracy of tests in predicting failures or outages simply have not been collected.

EPRI 1008459: Distribution Reliability Indices Tracking – Within the United States. May 2003.

Goals

- To provide an overview of historical distribution reliability trends in the U.S. based on publicly available data for System Average Interruption Frequency Index (SAIFI) and System Average Duration Index (SAIDI) performance indicators
- To highlight discrepancies in reliability reporting and discuss challenges to accurate and legitimate comparisons and applications of the data

Results

Data from 24 states and 65 utilities, spanning from 1992 to 2001, was analyzed to track the trend of distribution reliability in the United States. Key findings from this analysis follow:

- The 10-year average of SAIDI for all the utilities that exclude major events in their reporting is 107 minutes. This signifies that on average, a customer is expected to experience 107 minutes of sustained interruptions in a given year. Inclusion of major events increases the SAIDI indices on average by 100 percent to a maximum of 1200 percent.
- The 10-year average of SAIFI for all the utilities that exclude major events in their reporting is 1.1. This signifies that on average, a customer is expected to experience 1.1 sustained interruption events in a year. Inclusion of major events increases the SAIFI indices on average by 23 percent to a maximum of 109 percent.

A trend analysis was conducted using data from 1997 to 2001. In this analysis, the 75^{th} percentile showed a decreasing year-to-year trend of SAIFI from 1998 to 2001, but an increasing year-to-year trend of SAIDI from 1997 to 2000 that was reversed in 2001. No noticeable upward or downward trend appeared for the 50^{th} percentile of either SAIFI or SAIDI.

Year-to-year variability of a utility's reliability indices was quantified using the normalized standard deviation index, which is the ratio of standard deviation to mean. In this analysis, the media value of normalized standard deviation for SAIDI is 20.8 percent. Inclusion of major events in the reporting increased this variability to 65.4 percent. Moreover, the median value of normalized standard deviation for SAIFI is 16.6 percent. Inclusion of major events in the reporting increased this variability to 22.3 percent.

Intended Sector: Distribution

Relevant Components

Distribution Systems

EPRI 1009633: Nuclear Asset Management Database – Phase 2: Prototype LAMDA (Long-term Asset Management Database). December 2004.

Goal

- To provide plants with a validated methodology and generic database for easy access to data sources of generic reliability and cost parameters important to long-term equipment reliability planning and risk-informed asset management

Results

The failure rates of twenty component types calculated from expert elicited information in the EPRI Preventative Maintenance Basis Database (PMBD) fell within the scatter of the European Industry Reliability Databank (EIReDA) generic-data-based failure rates from plant experience (a factor of less than five more or less than the mean value). This leads to the conclusion that, at the least, a failure distribution based on PMBD can be combined with generic data and plant-specific data to give more robust reliability data. With further development, the PMBD methodology can become a primary source of reliability information, especially with regard to the effect of maintenance tasks on component failure rates.

Intended Sector: Nuclear

EPRI 1003188: Assessment of Component Reliability Databases for Turbo-XN. November 2001.

Goals

- To assess INPO's EPIX database and the NERC-GADS database as potential data sources for the proposed Turbo-XN outage interval optimization tool for non safety-related turbine generator systems
- To identify and describe the advantages and disadvantages of each database
- To develop criteria for the ideal database characteristics
- To define all program structure issues specific to extension of the Turbo-X methodology to nuclear plant maintenance planning

Results

The two databases each have strengths and weaknesses with regard to developing failure projections for Turbo-XN. An opportunity exists to combine the information from these two data sources in a way that takes advantage of the strengths of each source. The GADS database documents a large number of events and systematically identifies the failed components. The EPIX database provides more complete component descriptions including the manufacturer, model, and in-service date of individual components. Supplemental information from other databases, including NPRDS and UDI, might further enhance the component failure projections developed for Turbo-XN.

Intended Sector: Nuclear

Relevant Components

Turbines and Generators

EPRI 1002128: Transmission System Reliability Performance Metrics Requirements. December 2003.

Goals

- To assess industry reliability performance needs and underlying causes of non-standardization
- To suggest improvement initiatives by broad industry experts

Results

This report summarizes the need for a broad industry consensus to standardize the development of transmission reliability performance metrics and their underlying definitions and applications to power delivery processes. The report draws from significant industry expertise that has clearly expressed the benefits of these objectives as:

- Increased quality of industry reliability comparisons, i.e., benchmarking
- Increased transparency and accountability of system reliability performance and market interactions
- Ensured equity of performance based regulation (if enacted)

Intended Sector: Transmission

EPRI 1001971: Grid Equipment Reliability Study. December 2001.

Goals

- To understand current grid equipment reliability metrics and benchmarks practiced by utilities, to understand the importance utilities give to grid equipment reliability in the overall scheme of system reliability
- To identify gaps in current industry grid equipment reliability metrics
- To identify drivers for redefined/enhanced equipment reliability metrics

- To prepare a set of benchmarks that help utilities understand their strengths and weaknesses

Results

The study identified a gap in the current method of reporting grid equipment reliability. To fill this gap and permit development of meaningful benchmarks, a four-tiered approach to issues associated with grid equipment reliability was developed. This four-tiered approach defines a base set of data that drives grid equipment reliability metrics for utilities and external entities that provide oversight, such as system operators and regulators. These proposed metrics are a preliminary effort at capturing information required to operate and provide oversight to a transmission company while collecting the same base data.

Intended Sector: Transmission

Relevant Components

Lines, cables, circuit breakers, transformers, shunt reactor banks, shunt capacitor banks, series capacitor banks, synchronous and static compensators, busses, windings, surge arrestors, conductors

Criteria

This report assumes that devices of a similar type and class have an identical probability of failure due to historical trends. The following factors are not considered:

- Current condition of equipment
- Number of operations allowed on a device (for example voltage regulator or load tap changer)
- The number of fault operations a device should handle before inspection is required
- The number of fault and/or routine operations since the last diagnostic
- The number of fault and/or routine operations since the last internal inspection
- The load and/or fault duty of the device
- The number of routine switching operations before it is necessary to determine if repairs are needed
- The importance of a piece of equipment
- Equipment manufacturer and model

SAIDI and SAIFI are used to assess reliability for groupings of components including the following:

- Lines

- Line sections
- Transformer banks
- Capacitor banks
- Reactors

EPRI 1001827: Grid Equipment Reliability: Functional Requirements. December 2002.

Goals

- To identify and discuss the requirements for the development of a reference source of grid equipment reliability data to enable comparative and confidential analysis by participants
- To enable managers to make capital and O&M decisions more quickly and accurately through comparative analysis of grid equipment reliability impacts upon the utility and its customers

Results

This report establishes the functional requirements for a project in which participating utilities can evaluate the impacts of transmission unavailability to consumers and customers resulting directly from maintenance and asset strategies. This report identifies the requirements for the development of a reference source of grid equipment reliability data to enable comparative and confidential analysis by participants. The underpinnings of this reference database are precise definitions that ensure consistent comparison. These definitions include equipment categorization, equipment unavailability, unavailability impacts, restoration, and root cause categorization.

Utility operations and maintenance managers will benefit from the ability to more directly and comprehensively assess equipment reliability impacts upon system stakeholders, in order to optimize asset allocation, reduce cycle times for strategic evaluation of maintenance policies and reliability investments, and engage in enhanced comparative analysis from confidential multiple utility data. The project provides increased accountability in response to regulatory scrutiny over utility costs, reliability, non-discriminatory access, and market power withholding of congested transmission facilities.

Intended Sector: Transmission

Relevant Components

Major substation equipment categories (transformers, breakers, circuit switchers, synchronous and static compensators, reactors, capacitors, disconnects, potential transformers; and cable terminations)

Criteria

Data for this database was found in two primary data sets at utilities. The computerized maintenance management system, CMMS, would contain the “asset register” or a list of all the equipment as well as maintenance histories, repair data, etc. This data source is generally complete with respect to the installed assets, but may not contain state change information required to assess equipment or transmission unit availability.

The second data set is the system operations log that is populated with data from operational personnel either at the transmission dispatch center or at an independent system operator dispatch center. This data set generally contains all of the operations of transmission units; however equipment state changes may not specifically be identified. Equipment may not even be identified within this data set, since not all equipment is switch-able by operators.

Definitions of components are provided and are included in the report; therefore all data in the database will most likely conform to the definitions provided. An example of a definition of a component: Definition of Breakers – This includes equipment used for the termination of transmission units where power transfer is required and high speed fault interruption capability is also required on demand through the operation of the equipment trip and close functions. They types of breakers include dead tank and live tank, oil and gas insulated, air blast, etc. Breakers are unique because of the dual operating states and dual operating purpose – to connect or to isolate. These are split into two main subcategories: dead tank and live tank breakers.

However, it does not sound like the data is fully complete (report states that equipment state changes may be lacking).

EPRI 1007281: Analysis of Extremely Reliable Power Delivery Systems – A Proposal for Development and Application of Security, Quality, Reliability, and Availability (SQRA) Modeling for Optimizing Power System Configurations for the Digital Economy. April 2002.

Goals

- To develop a framework for understanding, assessing, and optimizing the reliability of powering new digital systems, processes, and enterprises. These energy needs will be met with a combination of electricity supply implementation techniques, new technologies, and new approaches, a process that must comprise all elements of the power delivery and end-use process – from the power plant, to the interconnecting systems, to the response of the digital systems, processes, and enterprises themselves.

Results

This report discusses how to understand and assess reliability; no actual equipment reliability data is provided.

Power Quality Levels. When quantifying the availability and quality of the electric power interface with digital systems, processes, and enterprises, it is important to define what constitutes a failure. Different digital systems respond differently to various voltage disturbances. It is appropriate to define different levels of quality because digital systems will respond differently. The definition must go beyond traditional utility definitions of reliability (interruptions greater than five minutes) and include shorter-duration events that cause disturbances to digital systems, processes, and enterprises.

Different levels of electric power interface are appropriate for different needs, so several levels of "quality" are defined. In order of the most sensitive definition of a failure to the least, the levels chosen are:

Level 1: Any voltage sags below those established by the Information Technology Industry Council (ITIC) in the guideline known as the "ITIC curve." A failure is any voltage:

- Below 70% of the nominal for greater than 0.02 seconds, or
- Below 80% of the nominal for greater than 0.5 seconds.

The steady-state values on the ITIC curve (voltage below 90% of nominal for more than 10 seconds) are excluded. The over voltage portion of the ITIC curve is also excluded.

Level 2: A failure occurs if the voltage drops below 70% of nominal voltage for more than 0.2

Level 3: A failure is an interruption of at least 1 second.

Level 4: A failure is an interruption of at least 5 minutes.

Digital systems, processes, and enterprises that are more sensitive would need better levels of quality. An electric power interface could be designed to deliver a mean time between failure (MTBF) of 5 years for level-4 loads and an MTBF of 1 year for level-1 applications. A whole facility might be given a certain MTBF of 1 year for interruptions longer than 5 minutes (level 4), but the server room might be designed to have a level-1 MTBF of 10 years.

Comparison of Alternate Quality/Reliability Arrangements: A Case Study Approach. To illustrate application of the power quality levels strategy and other important analysis techniques, this report applies SQRA analysis to several case studies with widely different types of digital systems, processes, and enterprises with varying electric power interface configurations. These include an internet data center, a textile manufacturer, a hospital, and a residential development.

A complete SQRA analysis to minimize costs includes several steps:

- Find the mean time between failures of each configuration.
- Estimate the annual equivalent configuration cost of each.
- For each configuration, find the annual outage cost based on the MTBF.
- Rank each scenario based on the total annual cost, which is the sum of the configuration costs and the outage costs.

Intended Sector: T&D

EPRI 1007442: Reliability Assessment of the Coronado Generating Station. March 2003.

Goals

- To demonstrate the effectiveness of predictive reliability assessment technology for evaluating and managing the economic risks associated with power plant reliability performance

Results

The Coronado Generating Station Reliability Assessment model provides the following:

- An integrated assessment of several plant reliability performance measures including plant availability, forced outage rate, frequency of forced outages, expected downtime from forced outages, plant capacity, unplanned capability loss factor, and several additional performance indicators
- An estimate of the annual frequency and consequences of each modeled scenario in terms of its impact on plant downtime, production losses, and replacement power costs associated with each modeled scenario
- As assessment of the primary contributors to several key plant reliability performance indicators to help determine the relative importance of plant systems and components

The model identifies those systems and components that contribute significantly to production losses as well as those that have very little risk significance. Sensitivity cases can be run on the model to quantify the impact of proposed plant design or operational changes on the costs associated with production losses. This “what-if” capability provides a powerful quantitative tool to investigate and prioritize reliability enhancement alternatives.

Intended Sector: Generation

Relevant Components

Project modeled coal conditioning, coal handling, fly ash handling, and bottom ash handling systems in detail

EPRI 1001691: Improved Reliability of Switched Capacitor Banks and Capacitor Technology. December 2002.

Goals

- To assess issues related to reliability of switched capacitor banks used in distribution systems
- To recommend strategies for technology-driven solutions that may include improved communication and control, switching methods, preventive and predictive maintenance tools, and enhanced capacitor technology that will help in improving capacitor bank reliability

Results

EPRI's utility survey found that experiences with capacitors ranged widely – roughly one-third found reliability of feeder capacitors very good, one-third found reliability typical of line equipment, and one-third found capacitors problematic. Those most highlighted issues capacitor banks were 1) misoperation of capacitor fuses and 2) controllers. The survey found that 21 out of 28 utilities have some problems with nuisance fuse operations on capacitor banks. A nuisance fuse operation is where the fuse is blown, but the capacitors themselves are still functional. With controllers of switched banks, a number of factors appear to contribute to the problem of capacitors not switching when they should. Of future technologies, the most interest is in pad-mounted capacitors: 40% of utilities are using pad-mounted capacitors and 60% envision using them in the future.

Intended Sector: Distribution

Relevant Components

Capacitor bank installations on distribution feeders

Criteria

Completeness of data: Unable to determine completeness of failures reported – for example, the survey asks about a number of failure modes, but does not specify whether this is a complete set of failure modes. The survey does ask about the manufacturer and model number for switched capacitor banks.

Rather than asking about specific failure rates, some of the survey questions asked about reliability in a more general sense. For example, "Have pad-mounted capacitors proved to be reliable?"

Maintenance data is not given on a specific basis either; rather data given is on a frequency basis (for example, how often maintenance is performed – once a year, once every 6 months, etc.)

Quality of data: Failure data should be able to be traced back to specific utilities or manufacturers. Twenty-seven utilities responded to the survey. The survey questions are recorded in the report though, so someone who knows more about capacitors should be able to tell.

Report states that there was a wide range of failure results reported.

EPRI 1006952: Reliability Assessment of North American Steam Turbines. April 2002.

Goals

- To compile reliability- and maintenance-related statistics on fossil-fueled steam turbines larger than 200 MW that are currently generating power in the continental United States

Results

Turbine design and performance characteristics show little dependence on geographic region except for total capacity and number of turbines available. Fuel types illustrate the most prominent demographic distinction between U.S. regions, with coal at 71 percent of the total fossil capacity -- the most prominent fossil-fuel source for steam-turbine power plants. Turbines with the most available capacity are between 20 and 50 years old, with the average turbine age at 38 years.

From available data, the failure of components in high-pressure turbines is responsible for the greatest loss of power capacity during deratings, whereas low-pressure turbines, valves, and high-pressure turbine problems contribute to the number of forced outages.

Groups that have high projected failure rates include half-speed turbines with a last-stage blade length greater than 35 inches (88.9 cm). Most of the considered turbine components are not expected to endure more than 30 to 40 years of on-line time without service. The larger turbines (600-1000 MW) tend to show shorter component lives than smaller turbines when the same components are considered, so these may be more likely to exhibit problems in the near future.

Intended Sector: Generation (Fossil)

Relevant Components

Turbine components, including bearings, buckets, blades, and high-pressure rotor shafts

EPRI 1004896: ERD Version 2.81.0016: Equipment Maintenance and Reliability Database Software. December 2003.

Goal

- To provide utilities a software tool that can be used to store and analyze equipment failure information at fossil power plants

Results

The Equipment Reliability Database (ERD) Version 2.81.0016 will store information about past equipment failures in order for power plant staff to better determine which are the correct maintenance tasks to perform, what is the correct equipment, and the correct scheduling for maintenance. After enough failure information is accumulated, it will be possible to predict how long equipment will last depending on its operating environment and maintenance history. The eventual goal is for EPRI to aggregate a comprehensive database of failure information for its members.

Fossil power plants are under constant pressure to reduce costs while improving reliability of their aging equipment. A proactive way to achieve these positive results amid these conflicting demands is to improve maintenance techniques used and increased emphasis on equipment reliability analysis. The PlantView module provides a tool through which the user can collect information about equipment condition/failures on a routine basis and analysis for adjustments in his or her maintenance basis or preventative maintenance program. The more effective streamlined reliability programs have a continuous feedback loop through analysis of failures both unexpected and those less than desirable conditions found during periodic inspections. This constant monitor/inspect and adjust process provides the continuous improvement necessary for an effective reliability program. When this module is added to a PlantView suite with an already populated Maintenance Basis file, the information fields are seamlessly filled with the previously entered data to simplify its use. This automation of data entry and the sorting capability provided allows the user to efficiently analyze the failure data for adjustment of their reliability program actions.

Intended Sector: Generation

EPRI 1004863: Component Failure Database, Version 2.0. December 2003.

Goal

- To provide a searchable database of critical fossil component failures

Results

This database documents failures on several critical fossil components. The database broadly defines "failure" as "the inability to safely perform its intended purpose." Thus, a failure could include a cracked part found during an outage as well as a component that fails catastrophically during operation. Where possible, the database defines the consequence level of the failure. The database contains significant technical details about the failure, or at least the information that is in the open literature or is commonly known. The database also has a search feature that allows queries to be performed easily for each component.

Intended Sector: Generation

EPRI NP-7410: Circuit Breaker Maintenance – Volume 1: Low-Voltage Circuit Breakers, Part 3: Westinghouse DB Models. December 1992.

Goals

- To establish a working-level understanding of breaker performance trends, reliability, and failure modes from which maintenance practices could be specified
- To consolidate industry guidelines, applicable standards, OEM recommendations, and industry hands-on experience that will aid in the development and implementation of a practical, cost-effective, and technically sound maintenance program for Westinghouse model DB circuit breakers

Results

Development of this guide involved an in-depth review of available operating experience and failure data; which was obtained from information sources within the nuclear power industry. IN addition, non-nuclear circuit breaker overhaul data was evaluated. Investigations were made into current industry practices, including a review of manufacturer's recommendations and industry standards. Finally, the collective information was used to develop maintenance recommendations and detailed guidance for inspection, test, and overhaul.

Contents of the guide include a description of Westinghouse's model DB breakers, their historical performance, failure mode identification, maintenance recommendations, inspection and test periodicity, and maintenance guidelines.

Intended Sector: Nuclear and Generation

Relevant Component

Low voltage Westinghouse DB circuit breakers

Criteria

Data utilized in this report is based on analysis of overhaul data and Nuclear Plant Reliability Data System (NPRDS) data.

Overhaul Data. The overhaul data is from breakers overhauled from September 1986 to December 1991. Breakers overhauled include those from non-safety related nuclear, fossil, marine, and general industry applications. Breaker model population was 12 different breakers, of four different models. Data from overhauls provide insight into the breakers' overall condition. The degradation mechanisms of failures are included, although root cause information is not included.

Overhauls were performed by Power Distribution Technology, Inc. (PDT), an independent vendor that specializes in overhauling and repairing circuit breakers. During the overhaul process, PDT extensively reviewed results of pre-overhaul and disassembly tests, inspections, and evaluations for each of the breakers as part of a Quality Assurance program that meets the requirements of 10CFR50 Appendix B. While the number of breakers reviewed is not that large, a large quantity of information about each breaker was available.

Breakers were broken down into well-defined subcomponents and 65 different types of deficiency modes were also defined.

NPRDS Data. The NPRDS is an industry source of historical data used to evaluate the performance of nuclear power plant subcomponents. The NPRDS data are collected from failure reports. 221 failure reports were analyzed, which resulted in a total of 237 failures. Failures were categorized by breaker operation, breaker model, and breaker subcomponent. Suspected degradation mechanisms are listed and the breaker average age at failure is also included.

EPRI 1002954: Guide for Predicting Long-Term Reliability of Nuclear Power Plant Systems, Structures and Components. December 2002.

Goals

- To provide plant engineers with improved methods and guidance for predicting long-term failure rates for input to systems, structures, and components (SSC) life cycle management evaluations

Results

This report reviews generic industry databases and data types generally available (and unavailable). The report provides a roadmap to a variety of nuclear industry reliability and event data sources, many of which include significant amounts of electrical equipment. It also describes statistical methods for interpreting failure rate data. Long-term failure rate prediction methods are illustrated by example applications to compressors (active component) and buried service water piping (passive component) in the Wolf Creek nuclear power plant. The resulting methods are intended to help LCM planners improve the credibility and reduce the uncertainty of long-term SSC failure predictions.

Intended Sector: Nuclear

Relevant Components

Generation equipment (specific data included for compressors and buried service water piping)

EPRI 1007422: Life Cycle Management Planning Sourcebooks – Volume 4: Large Power Transformers. March 2003.

Goal

- To provide engineers (or their expert consultants) with a compilation of the generic information, data, and guidance typically needed to produce a plant-specific LCM plan for large transformers

Results

This sourcebook contains information on large transformers such as Generator Step-Up (GSU), Unit Auxiliary Transformer (UAT), and Startup Auxiliary or Reserve Auxiliary Transformers (RATs/SATs). It also contains information on transformer accessories and monitoring devices for transformer protection and performance. Information includes performance monitoring issues, component aging mechanisms, aging management maintenance activities, equipment upgrades, and replacements. Based on this information, alternative LCM plan strategy guidance has been developed, along with recommendations. The plan strategy guidance provides information for implementing cost-effective LCM planning for large transformers. The sourcebook includes an extensive list of references, many of which are EPRI reports related to the maintenance and reliability of large power transformers.

Intended Sector: Nuclear

Relevant Components

Large Transformers (2.5 to 1500 MVA at a high voltage range of 115 to 765 kV and a lower voltage of 4.16 to 13 kV)

Criteria

Some data is found in SOER 02-3 (70 events associated with large main power transformers since 1996). The type of failure event is recorded (i.e. fire/explosion, transformer trip, etc.). Also, the most likely cause of the event is recorded (i.e. bushing failure, ground fault, insulation failure/short circuit, pressure relay failure, etc.). This data is generic and may not be traceable back to the specific plants.

Data from Hartford Steam Boiler (HSB) is also used in this report. HSB analyzed the transformer failures that occurred in 1975, 1988, and 1998 for various industries such as power plants, commercial buildings, manufacturing and metal processing facilities. Total failure data and attributed failure modes are listed.

There is a relatively large amount of failure data available, but the data is not necessarily complete. No manufacturer data, maintenance data, is available.

EPRI 1007426: Life Cycle Management Planning Sourcebooks – Volume 7: Low Voltage Electrical Distribution Systems. February 2003.

Goals

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

Results

This sourcebook contains information on Low Voltage Distribution Systems (LVDS) and particularly their associated circuit breakers. Information compiled includes performance monitoring issues, component aging mechanisms, aging management maintenance activities, equipment upgrades, replacements, and most importantly, technical obsolescence assessments. The sourcebook includes an extensive list of references, many of which are EPRI reports related to the maintenance and reliability of circuit breakers.

Intended Sector: Nuclear

Relevant Components

Low voltage electrical distribution systems; circuit breakers

Criteria

Data from the EPIX and NPRDS databases are used in this report. A specific study of 480 Volt distribution systems in the EPIX database shows that 500 failures were reported from 1997 to 2002. Because the data entry in EPIX is far more detailed and explicit than that of NPRDS, it lends itself to better statistical analysis. In terms of completeness, it was found that not all of the failure events were reported in the EPIX database. A failure report is filed when a functional failure occurred that caused a loss of the system or train function. The Maintenance Rule requires reporting of Maintenance Preventable Functional Failures (MPFFs) only and failures due to design, fabrication, installation and assembly usually are not deemed to be MPFFs. The data clearly shows some inconsistency in reporting failures and the different thresholds utilities may apply to the definition of breaker failure. Failure modes are available.

Failure rate data is also taken from IEEE 493-1997, representing general industrial breaker data. Report says that utility data is not well represented and surveys did not include safety-related equipment.

Report gives a good description of component boundaries.

EPRI 1002637: TRELSS Application Manual – For Cascading Failure, Reliability, and Deterministic Analysis. October 2003.

Goals

- To aid in the evaluation of power network reliability using enumeration of generation and transmission contingencies

Results

TRELSS expands on traditional contingency analysis by modeling protection system response to faults. Contingency analysis is widely understood to mean independent component outages either singly or in combination. The response of the protection system to faults results in isolation of a set of components termed Protection and Control Group (PCG). TRELSS identifies PCGs from specified breaker locations and provides the user with the ability to simulate real-world response to faults. In fact, PCG outages are the greatest single source of system load loss in terms of both frequency and severity.

TRELSS computes reliability indices using a contingency enumeration approach, which involves selection and evaluation of contingencies, classification of each contingency according to specified failure criteria and accumulation of reliability indices. Three basic methods of reliability assessment are available: the System Problem Approach and Contingency Screening Approach quantify reliability in terms of frequency, probability, and severity of overloads and voltage violations and the Capability Approach, which includes application remedial actions including load curtailment, attempts to quantify system reliability all in terms of load loss indices consisting of probability, frequency, Expected Unserved Energy (EUE), Expected Unserved Demand (EUD), etc.

Intended Sector: Transmission

Relevant Components

Bulk power transmission systems; rapid screening of large portions of the transmission grid

The Electric Power Research Institute (EPRI)

The Electric Power Research Institute (EPRI), with major locations in Palo Alto, California, and Charlotte, North Carolina, was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together member organizations, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of power generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total R&D program.

Together…Shaping the Future of Electricity

Program: 1008553

Power Delivery Asset Management

Printed on recycled paper in the United States of America

Electric Power Research Institute • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com