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Minimum Recommendations to Maintain Electric Motor Reliability

2019 TECHNICAL REPORT

Minimum Recommendations to Maintain Electric Motor Reliability

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ABSTRACT

Electric motor reliability is dependent on many variables. Original design, operating environment, physical location, operating requirements, age of motor, and maintenance activities all play a role in maintaining motor reliability. When adjustments are made in maintenance activities, the risk impact must always be considered. Some changes lower risk while other may increase risk. Each motor program owner must understand the impact of changes and understand the associated risk. The challenge is to balance required motor reliability with maintenance cost to ensure that each motor has the most effective maintenance performed with the most cost effectiveness for the utility.

Because of the many different motor designs and operating requirements, maintenance activities can vary for each motor. Performance of maintenance activities should be based on their effectiveness of maintaining motor reliability for the life expectancy of the motor.

Keywords

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PRIMARY AUDIENCE: Motor program owners, component engineers, component specialists

SECONDARY AUDIENCE: Maintenance engineers, operations, planning

KEY RESEARCH QUESTION

EPRI has provided recommendations for motor maintenance, repair, procurement, and program management related to electric motor use in power plants. What impact have these recommendations had on electric motor performance from a reliability perspective? What recommendations can be reduced or eliminated with limited impact on motor reliability?

RESEARCH OVERVIEW

Initially, available industry performance and maintenance data were reviewed to understand past performance. Also, a survey of motor program owners was conducted to understand present performance and the maintenance practices to achieve level of reliability that motors have accomplished. There were interviews and group discussions during industry meetings to review preliminary findings.

KEY FINDINGS

- Motor design, including that of auxiliary equipment essential to the motor's functioning, should be considered before making any changes to the preventive maintenance program.
- A motor's operating environment should be considered when adjusting maintenance intervals.
- Motors critical to plant operation should receive maintenance and inspections to ensure their reliability.
- A motor's operating history is essential when adjusting maintenance programs. Avoid making changes that extend operation but could be a setup for catastrophic failure (such as omitting oil cooler maintenance).
- Technology has not progressed to the point where all failure mechanisms can be identified by condition monitoring.
- Motor program owners must understand the risk associated with adjustments in maintenance tasks.
- Scheduled refurbishments using the input from condition monitoring will enhance maintenance programs.
- Maintenance and monitoring activities, refurbishments, and available spares should always be part of an effective maintenance program.

WHY THIS MATTERS

Electric utilities hoping to lower their operating and maintenance costs must understand whether some activities can be extended or eliminated without impacting electric motor reliability. It is also important to improve condition monitoring programs so that plants can effectively monitor degradation, in order to ensure continued reliability of their motors.

HOW TO APPLY RESULTS

Motor program owners should use the results of this report as a basis to determine if adjustments can be made to their electric motor maintenance tasks. The focus of the project was to keep economic viability in mind with limited impact on reliability.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- The Large Electric Motor Users Group supported the development of this report and is a good resource for electric motor program owners who want to learn about and contribute projects related to electric motors.
- The results of this report would be useful to any owners of electric motors that are reviewing and/or adjusting their motor maintenance activities.

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CONTENTS

ABSTRACT ..... **V**

EXECUTIVE SUMMARY ..... **VII**

1 **INTRODUCTION** **1-1**

1.1 Purpose 1-1

1.2 Scope 1-2

1.3 Exceptions 1-2

2 **INDUSTRY MOTOR PROGRAM SURVEY RESULTS AND MOTOR FAILURE REVIEW** **2-1**

2.1 Survey Results 2-1

2.2 Summary of Nuclear Plant Survey Results 2-12

2.3 Motor Trends - INPO Consolidated Events Systems (ICES) – 1Q-2011 – 2Q-2016 2-12

3 **MINIMUM RECOMMENDATIONS TO MAINTAIN MOTOR RELIABILITY** **3-1**

3.1 PMs for Low Voltage (<600 Vac) motors (<100 HP (75 kW)) 3-2

3.2 PMs for Motors of 100 – 499 HP (75 – 372 kW) (Random and Form Wound) (<600V – 6.9kV) 3-2

3.3 PMs for Medium Voltage Motors ≥ 500 HP (≥373 kW) (2.3kV – 6.9kV) 3-3

3.4 PMS for Motors ≥ 500 hp (≥373 kW) and > 6.9kV 3-3

3.5 PMs for Environmentally Qualified (EQ) Motors (Random and Form Wound) 3-4

3.6 The Need for Motor Refurbishment 3-8

3.7 Motor Refurbishment Recommendations 3-10

4 **MOTOR MONITORING** **4-1**

4.1 Periodic and Continuous Monitoring 4-1

5 **CONCLUSIONS** **5-1**

6 **REFERENCES AND BIBLIOGRAPHY 6-1**

6.1 References 6-1

6.2 Bibliography 6-2

A **HARDWARE ENHANCEMENTS A-1**

B **VULNERABILTY ANALYSIS USING PMBD B-1**

LIST OF FIGURES

Figure 2-1 Chart for Table 2-2 (Data Shown in Percent) <600 V Motor Failures in Past 5 Years 2-2
Figure 2-2 Chart for Table 2-3 (Data Shown in Percent) 2.3kV – 15kV Motor Failures in Past 5 Years 2-3
Figure 2-3 Chart for Table 2-4 Motor Evaluations to Support Plant License Renewal 2-4
Figure 2-4 Chart for Table 2-5 Most Effective Preventive Maintenance for Low Voltage (<600V) Motors 2-5
Figure 2-5 Chart for Table 2-6 Most Effective Conditioning Monitoring for Low Voltage (<600V) Motors 2-6
Figure 2-6 Chart for Table 2-7 Most Effective Preventive Maintenance for Medium Voltage (2.3kV – 15kV) Motors 2-7
Figure 2-7 Chart for Table 2-8 Most Effective Condition Monitoring for Medium Voltage (2.3kV – 15kV) Motors 2-8
Figure 2-8 Chart for Table 2-10 What Percentage of Your Medium Voltage (2.3kV – 15kV) Motors have been Refurbished in the Last 20 Years 2-10
Figure 2-9 Chart for Table 2-11 What Percentage of Your Medium Voltage (2.3kV – 15kV) Motors have been Rewound in the Last 20 Years 2-11
Figure 2-10 Motor Events (<100 HP) and Their Effects on Power Generation 2-13
Figure 2-11 100 – 499 HP Motor Events from 1Q-2011 – 2Q-2016 2-14
Figure 2-12 All Motor Events - Number of Events Affecting Power Generation 2-14
Figure 2-13 Motor Related Lost Generation by Horse Power 2-15
Figure 2-14 Motor Events (500 HP and greater) and Loss Generation by System 2-16
Figure 2-15 Unit Impact of Motor Events (1Q-2011 – 2Q-2016) 2-17
Figure 2-16 Motor Events Affecting Power Generation by Problem Type 2-18
Figure 2-17 Motor Component Failure and its Effect on Power Generation 2-19
Figure 2-18 Direct Cause of Motor Events Affecting Power Generation 2-20
Figure A-1 Pressure Cutoff Grease Fill Fitting A-1
Figure A-2 Grease Relief Drain Plug A-1
Figure A-3 Automatic Grease Device A-2
Figure A-4 Example of One Type of 8kV Removable Motor Lead/Cable Connection Insulator A-2
Figure A-5 Example of a Flared Barrel Motor Lead Lug A-2
Figure A-6 Example of a Motor Start Counter and Motor Run Timer A-3
Figure B-1 PMBD Vulnerability Comparison for Low Voltage Critical Motors B-2

Figure B-2 PMBD Vulnerability Comparison for Low Voltage Noncritical Motors B-3
Figure B-3 PMBD Vulnerability Comparison for Medium Voltage Horizontal Critical Motors B-4
Figure B-4 PMBD Vulnerability Comparison for Medium Voltage Horizontal Noncritical Motors B-5
Figure B-5 PMBD Vulnerability Comparison for Medium Voltage Vertical Critical Motors B-6
Figure B-6 PMBD Vulnerability Comparison for Medium Voltage Vertical Noncritical Motors B-7

LIST OF TABLES

Table 2-1 Industry Surveys and Motor Engineer Discussions – What EPRI documents were used to develop your motor maintenance program? 2-1

Table 2-2 Industry Surveys and Motor Engineer Discussions – What has been your predominant failures with low voltage (<600V) motors over the past 5 years? 2-2

Table 2-3 Industry Surveys and Motor Engineer Discussions – What has been your predominant failures with medium voltage motors (2.3kV – 15kV) over the past 5 years? 2-3

Table 2-4 Industry Surveys and Motor Engineer Discussions – What evaluations have you performed on your motors to support plant license renewal for 20 plus years of operation? 2-4

Table 2-5 Industry Surveys and Motor Engineer Discussions – What Preventive Maintenance have been the most effective in maintaining low voltage motors? 2-5

Table 2-6 Industry Surveys and Motor Engineer Discussions – What Condition Monitoring have been the most effective in maintaining low voltage motor reliability? 2-6

Table 2-7 Industry Survey and Motor Engineer Discussions – What Preventive Maintenance(PM) has been the most effective in maintaining medium voltage motors? 2-7

Table 2-8 Industry Surveys and Motor Engineer Discussions – What Condition Monitoring have been the most effective in maintaining medium voltage motor reliability? 2-8

Table 2-9 Industry Surveys and Motor Engineer Discussions – Do you feel your motor program provides acceptable reliability? – Explain 2-9

Table 2-10 Industry Surveys – What percentage of your medium voltage motors have been refurbished in the last 20 years? 2-10

Table 2-11 Industry Surveys – What percentage of your medium voltage motors have been rewound in the last 20 years? 2-11

Table 3-1 Recommended Minimum Activities for Motor Maintenance 3-5

Table 3-2 Recommendations on Motor Refurbishment, Rewind, Stator Core, and Rotor Replacement 3-11

Table 4-1 Minimum Recommended Periodic and Continuous Monitoring for Motors 4-2

1
INTRODUCTION

All electric motors require a certain amount of maintenance activities to maintain an acceptable level of reliability.

This guide provides a review of the preventive maintenance recommendations that have been provided over time in EPRI documents such as NP-7502 [1], *Electric Motor Predictive and Preventive Maintenance*, 1003095 [2], Electric Motor Tiered Motor Maintenance Program, and others.

When the previous EPRI reports on electric motor maintenance were written, motor reliability was of paramount importance such that cost was only a secondary thought. However, EPRI 1003095 [2] provided a method to assist plants in focusing their maintenance resources to a level commensurate with a motor's safety and economic significance.

Motor maintenance guidance provided in the past was and is sound. However, plants age, certain plant requirements and criteria that were used in previous years has changed, thus, requiring a reevaluation of past guidance.

In reviewing the implementation of past guidance, we will continue to evaluate and refine existing guidance to ensure that it meets or exceeds changes that are occurring in the industry.

1.1 Purpose

It is intended that this guide be used as basis for identifying minimum maintenance activities to ensure an acceptable level of motor reliability. Evaluations of existing maintenance programs, surveys, other industry motor failure data, and plant license extension for an additional 20 plus years of operation were used in the development of this guide. This guide should be used in conjunction with original equipment manufacturer (OEM) recommended practices on motor maintenance, additional EPRI guides pertaining to motor maintenance, refurbishment, and rewinds, and industry standards for motors.

This guide provides the elements of an effective maintenance program for electric motors which includes:

- Visual Inspection
- Testing
- Refurbishment Options
- Replacement and/or Rebuild of Major Components
- Replacement of Complete Motor

1.2 Scope

This guide is applicable to all motors important for plant operation. These motors can be low or medium voltage motors of ac squirrel cage induction, synchronous, or dc design including Safety Related Non-Environmentally Qualified (EQ) and EQ motors.

1.3 Exceptions

When using this guide, care should be taken to ensure that future revisions to standards and/or regulations referenced in this guide are evaluated for additional or different recommendations.

While this document contains a sound methodology that can be used to manage maintenance and reliability of electric motors, it does not supersede plant and/or regulatory requirements and commitments for maintenance. This document is considered a best practice guidance document and not a standard.

This guide is not applicable for submersible, hermetically sealed, or canned pump motors due to their specialized and unique designs.

2
INDUSTRY MOTOR PROGRAM SURVEY RESULTS AND MOTOR FAILURE REVIEW

Industry survey, discussions with motor engineers, and other industry resources were used to determine which motors have failed and what types of failures were occurring in the nuclear industry.

2.1 Survey Results

The following tables presents the results of the survey as well as discussions with motor engineers during recent LEMUG meetings:

Table 2-1
Industry Surveys and Motor Engineer Discussions – What EPRI documents were used to develop your motor maintenance program?

Motor Maintenance Programs
NP-7502, *Electric Motor Predictive and Preventive Maintenance Guide* [1]
1003095, *Electric Motor Tiered Maintenance Program* [2]
EPRI Preventive Maintenance Basis Database (PMBD) [23] and PM Templates from TR-106857, V8 [3], V9 [4], V10 [5], and V11 [6].
Motor Refurbishment
1016679, *Repair and Reconditioning Specification Guidance for AC Squirrel-Cage and Salient Pole Synchronous Motors with Voltage Ratings of 2.3 to 13.2 kV: Revision 1of 1000897* [7]
3002008052, *Repair and Reconditioning Specification for AC Squirrel-Cage Motors with Voltage Ratings of up to 600V: Revision of 1008964* [8]
3002005357, *Squirrel-Cage Rotor Inspection, Testing, Repair, and Replacement Consideration* [9]
Specialized Programs
3002008049, *Moisture Management of Electric Motors: Prevention, Detection, and Restoration Guidance* [10]
3002000644, *Motor Management Guide Supporting Plant License Renewal Including Environmental Qualification Considerations* [11]
1021780, *Manual of Bearing Failures and Repair in Power Plant Rotating Equipment – Revision 1 of GS-7352* [12]
1016680, *Guide for the Performance of On-Site and Vendor Inspections of Electric Motors* [13]
3002000527, *Critical Motor Refurbishment and Procurement Checklist* [14]
3002003261, *Guide for Sample Stator Coil Inspection and Testing During Motor Rewinds and Manufacturing* [15]
1021427, *Guidance for Developing an Electric Motor Specialist* [16]

Table 2-2
Industry Surveys and Motor Engineer Discussions – What has been your predominant failures with low voltage (<600V) motors over the past 5 years?

Winding Failures -50%
Bearing Failures - 50%
Motor Leads - 5%
Comments
Note: There appears to be an equal number of winding and bearing failures on low voltage motors in the past 5 years. Most of the failures have occurred on non-critical motors. Age appears to be a main contributor for the winding and motor lead failures whereas run-to-failure motors have experienced most of the bearing failures.

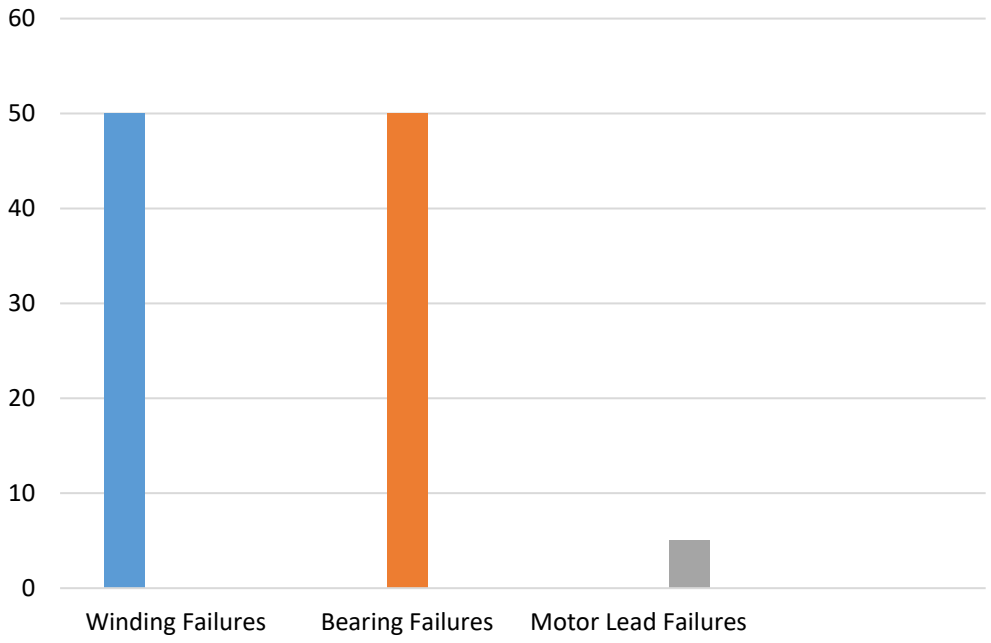


Figure 2-1
Chart for Table 2-2 (Data Shown in Percent) <600 V Motor Failures in Past 5 Years

Table 2-3
Industry Surveys and Motor Engineer Discussions – What has been your predominant failures with medium voltage motors (2.3kV – 15kV) over the past 5 years?

Bearing Failures - 60%
Winding Failures - 30%
Water Intrusion causing corrosion damage to rotor - 7%
Motor Leads - 3%
Comments
Bearing failures appear to be causing more motor failures based on the survey and discussion results followed by winding failures for medium voltage motors. Water intrusion is more of a problem with coastal and cold climates motors due to harsher environmental conditions. Winding failures have less failure rate because many of the medium voltage motors have been rewound due to winding degradation found during refurbishment.

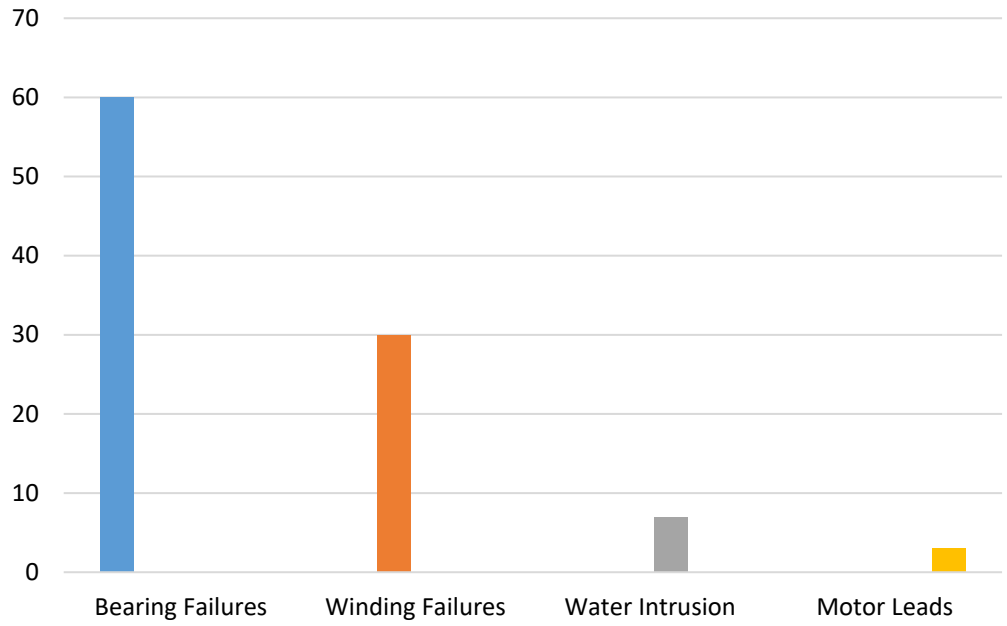


Figure 2-2
Chart for Table 2-3 (Data Shown in Percent) 2.3kV – 15kV Motor Failures in Past 5 Years

Table 2-4
Industry Surveys and Motor Engineer Discussions – What evaluations have you performed on your motors to support plant license renewal for 20 plus years of operation?

Condition Assessment
Life Cycle Management
EQ Life Evaluation
Comments
Some of the engineers indicated that EPRI 3002000644 - Motor Management Guide Supporting Plant License Renewal Including Environmental Qualification Considerations [11] was used to assist in the motor evaluations for plant life extensions.

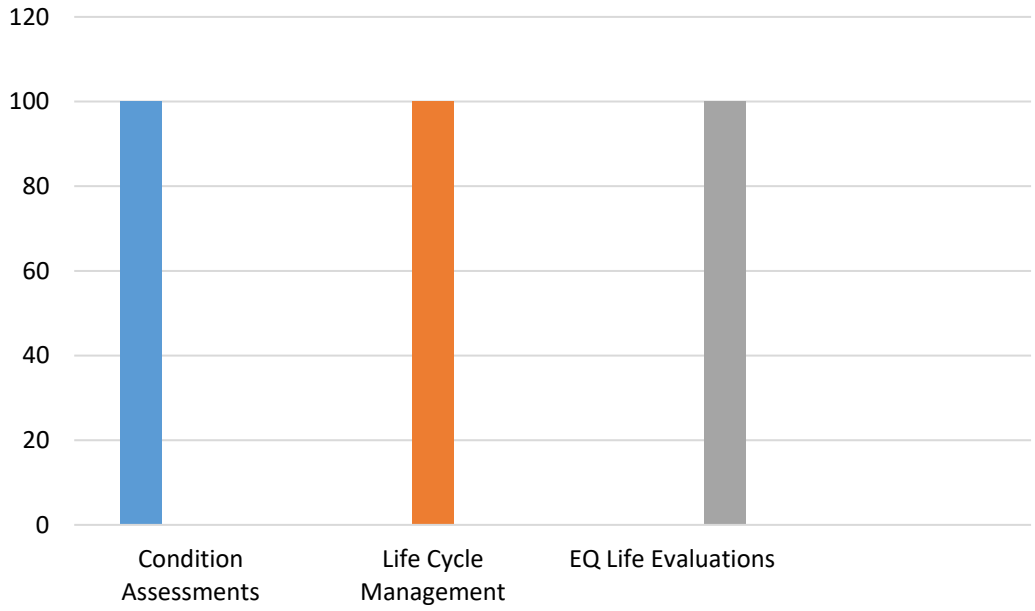


Figure 2-3
Chart for Table 2-4 Motor Evaluations to Support Plant License Renewal

Table 2-5
Industry Surveys and Motor Engineer Discussions – What Preventive Maintenance have been the most effective in maintaining low voltage motors?

Re-greasing of rolling element bearings - 90%
Visual inspections - 5%
Electrical testing - 5%
Comments
The results of the survey and engineer discussion indicated that the most effective PM activity for low voltage motors was a good re-greasing program and bearing maintenance. Most were using the re-greasing guidance of EPRI Report NP-7502 Appendix B [1] as a basis for their re-greasing program. A few performed visual inspections and electrical testing but did not list these as the most effective PM.

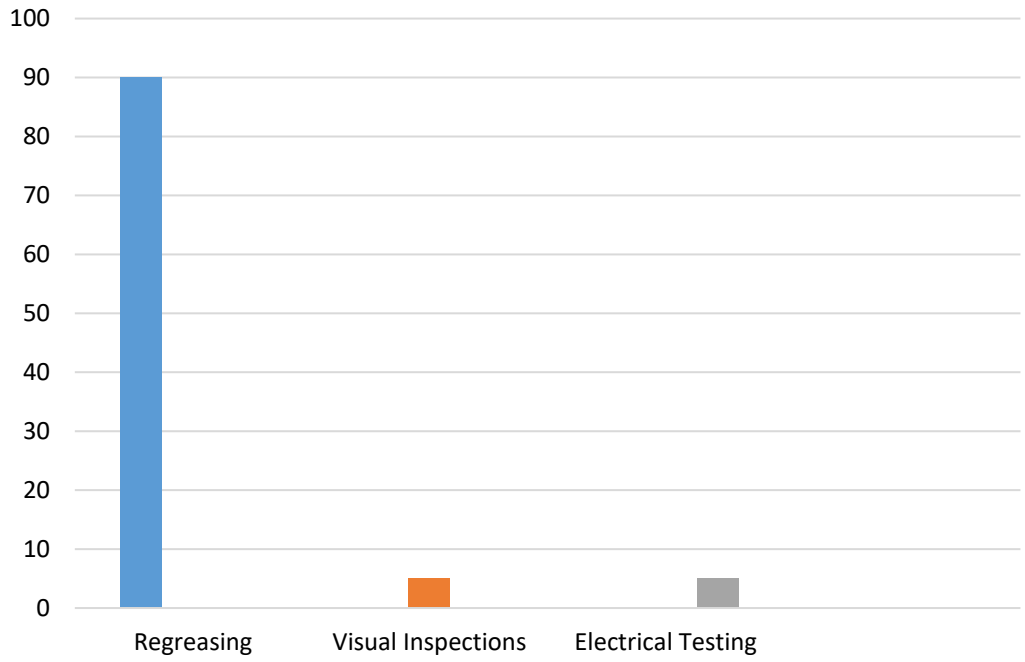


Figure 2-4
Chart for Table 2-5 Most Effective Preventive Maintenance for Low Voltage (<600V) Motors

Table 2-6
Industry Surveys and Motor Engineer Discussions – What Condition Monitoring have been the most effective in maintaining low voltage motor reliability?

Vibration Monitoring - 100%
Thermography -5% (coupled with vibration monitoring)
Comments
All survey results and engineer discussions indicated that vibration monitoring was the most effective condition monitoring activity that can be performed on a low voltage motor to maintain reliability. A few used thermography in addition to vibration monitoring.

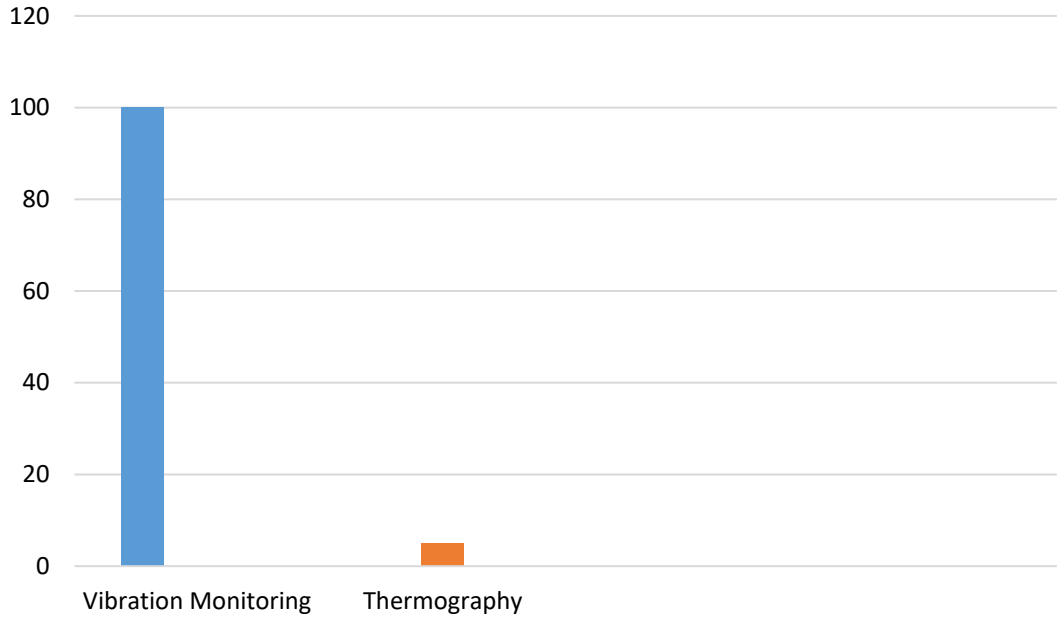


Figure 2-5
Chart for Table 2-6 Most Effective Conditioning Monitoring for Low Voltage (<600V) Motors

Table 2-7
Industry Survey and Motor Engineer Discussions – What Preventive Maintenance(PM) has been the most effective in maintaining medium voltage motors?

Scheduled Refurbishments – 100%
Electrical Testing – 30%
Comments
All of the survey results for this question listed scheduled refurbishments as the most effective PM activity in maintaining medium voltage motors. A few listed electrical tests in addition to scheduled refurbishments. Electrical tests checked on the survey were primarily winding resistance and insulation resistance. No high potential tests were listed in the survey results.

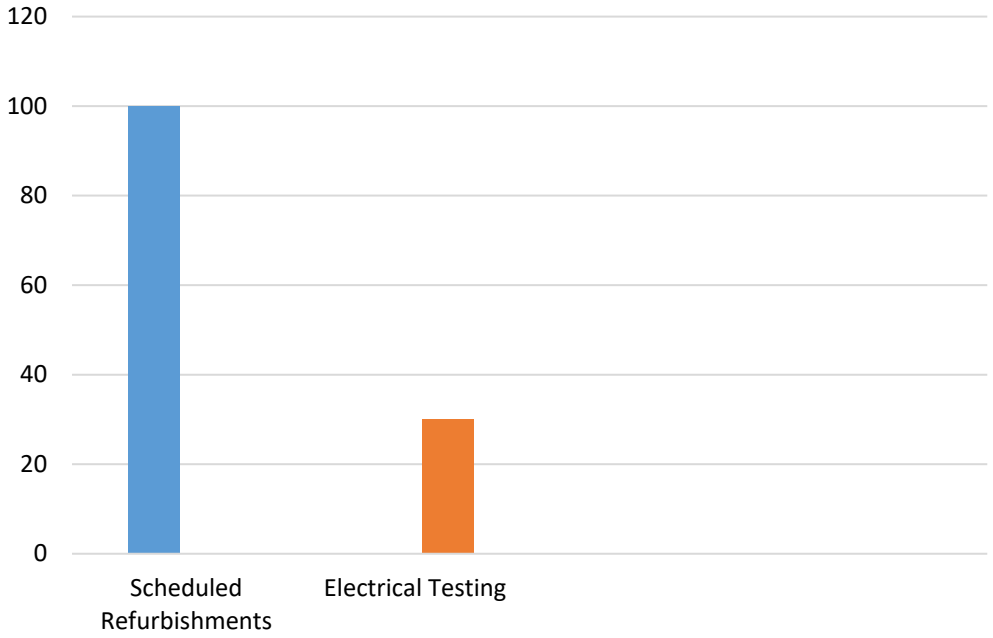


Figure 2-6
Chart for Table 2-7 Most Effective Preventive Maintenance for Medium Voltage (2.3kV – 15kV) Motors

Table 2-8
Industry Surveys and Motor Engineer Discussions – What Condition Monitoring have been the most effective in maintaining medium voltage motor reliability?

Vibration Monitoring – 100%
Temperature Monitoring -100%
Oil Analysis for Fluid Film Bearings – 100%
Current Signature Analysis 10%
Thermography – 10%
Partial Discharge Testing – 5%
Very Low Frequency Testing – 1%
Comments
The three most important condition monitoring activities listed in the surveys were vibration monitoring, temperature monitoring, and oil analysis for fluid film bearings. These three condition monitoring activities have always been considered the most important for maintaining medium voltage motor reliability. A few responses on the survey listed current signature analysis, thermography, partial discharge, and very low frequency testing as important.

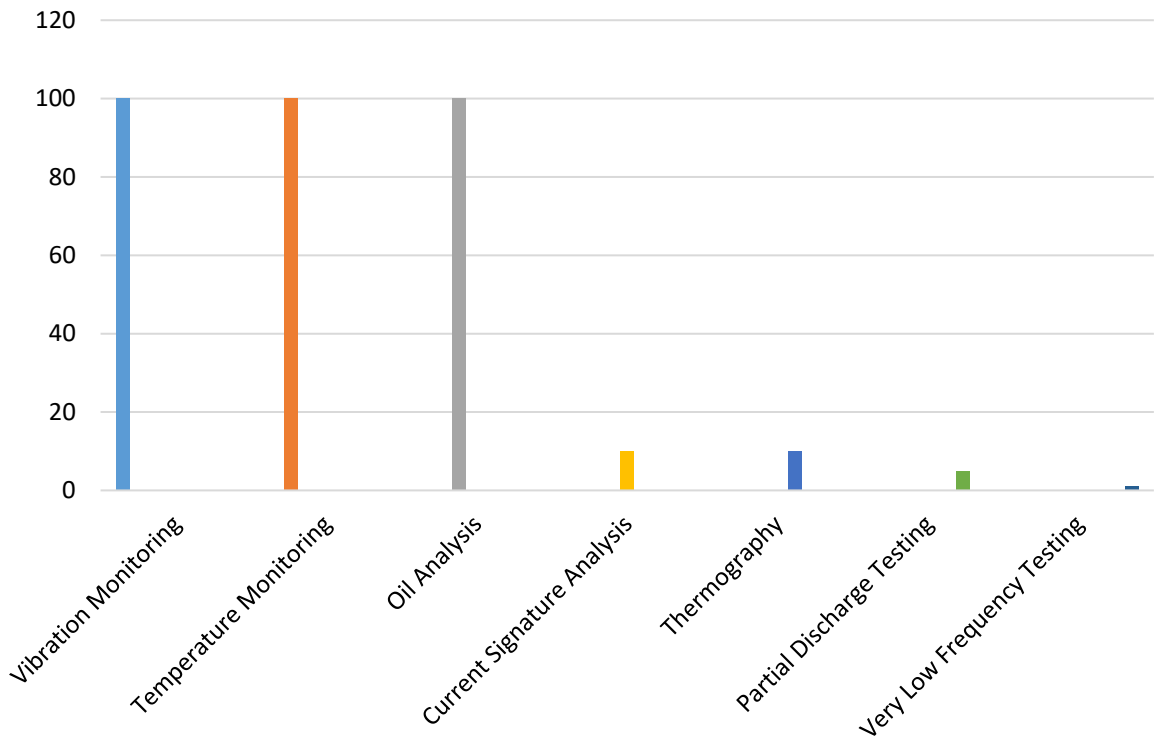


Figure 2-7
Chart for Table 2-8 Most Effective Condition Monitoring for Medium Voltage (2.3kV – 15kV) Motors

Table 2-9
Industry Surveys and Motor Engineer Discussions – Do you feel your motor program provides acceptable reliability? – Explain

All survey results and discussions indicated that each motor engineer feels that the present motor program in place provides acceptable reliability.
The survey results and discussions with motor engineers indicated that a large part of the motor reliability is because of scheduled refurbishments.
Concerns listed on the survey results is that the reliability may not remain the same as maintenance budgets are being cut and proactive maintenance (i.e., scheduled refurbishments) of large motors is reduced. This concern coupled with the aging of the motors may lead to an eventual increase in significant motor failures as all degraded conditions cannot be detected with condition monitoring. See Section 3.6 of this report for discussion on refurbishment.
Comments
Because most nuclear plants have been approved for plant license renewal, the aging of the large motors has to be addressed to maintain an acceptable level of reliability for the next 20 plus years of operation. EPRI LEMUG published a report in 2013 – Report 3002000644 - Motor Management Guide Supporting Plant License Renewal Including Environmental Qualification (EQ) Considerations *[11] to address this concern. [11] provides a sound methodology for ensuring aging degradation of motors is addressed as well as information on extending the EQ life.*

Table 2-10
Industry Surveys – What percentage of your medium voltage motors have been refurbished in the last 20 years?

Results of the Industry Survey – **Each percentage listed below is from one survey (10 surveys – 10 plants)**
100%
95%
90%
90%
85%
60%
60%
50%
50%
40%
Comments
As shown by the percentages from the surveys the motor reliability and the "Yes" answer in Table 2-9 about the motor engineers feeling about their present motor program providing an acceptable level of motor reliability is based on a high percentage of their motors being routinely refurbished. It is also worth noting that there are large motors installed that have not been refurbished but are expected to operate for the next 20 plus years to support plant license renewal.

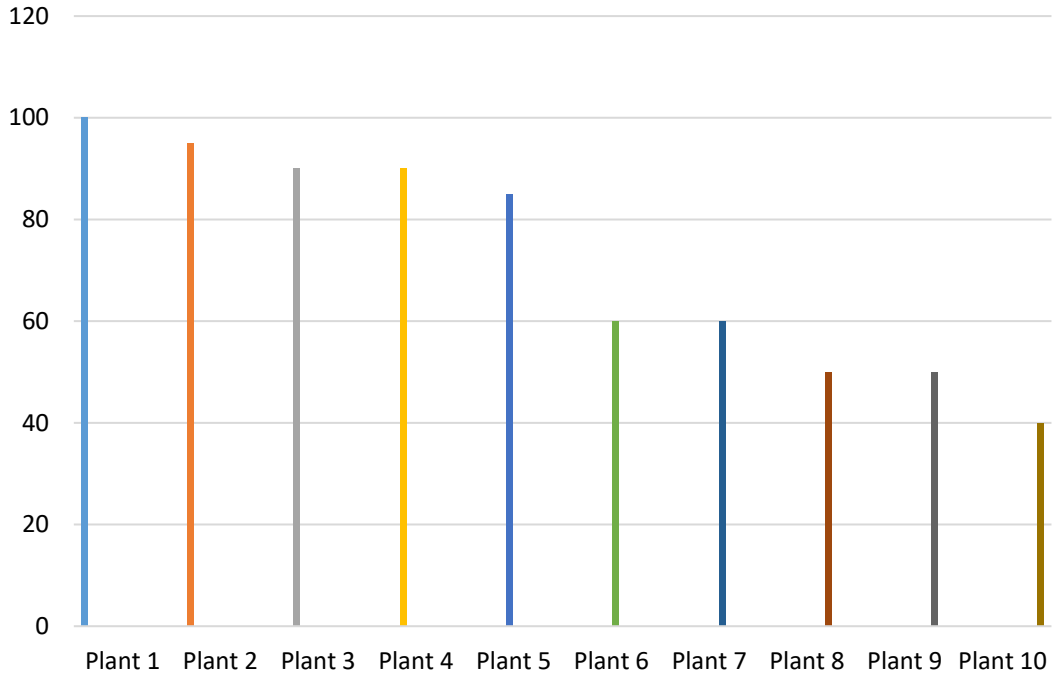


Figure 2-8
Chart for Table 2-10 What Percentage of Your Medium Voltage (2.3kV – 15kV) Motors have been Refurbished in the Last 20 Years

Table 2-11
Industry Surveys – What percentage of your medium voltage motors have been rewound in the last 20 years?

Results of the Industry Survey – **Each percentage listed below is from one survey (10 surveys – 10 plants)**
100%
90%
75%
60%
50%
50%
40%
17%
10%
0%
Comments
The percentages shown above reflect the proactive approach of 7 of the 10 plants to rewind the medium voltage motor population to address degradation issues with the windings which includes aging degradation. Winding replacement always requires a full refurbishment as the motor is completely disassembled to remove the stator. Without this proactive approach for both refurbishment and winding replacement the amount of large motor failures in the nuclear industry would be much greater. It is a concern of the individuals that were surveyed that if the present methodology for large motor refurbishment which typically identifies the need to rewind is eliminated or drastically reduced then motor failures will increase on those that have not been rewound.

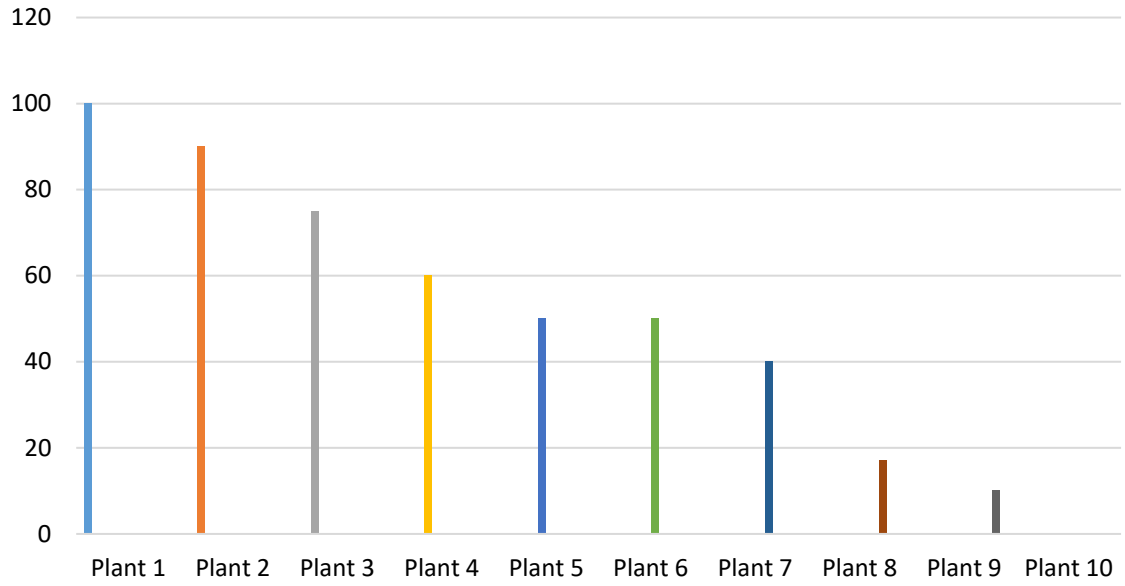


Figure 2-9
Chart for Table 2-11 What Percentage of Your Medium Voltage (2.3kV – 15kV) Motors have been Rewound in the Last 20 Years

2.2 Summary of Nuclear Plant Survey Results

Based on the survey results and discussions with motor engineers about their motor programs a few trends were observed.

- Low voltage motors (<600 Vac) are maintaining an acceptable level of motor reliability by performing PM activities on the bearings (i.e., re-greasing, bearing replacement when necessary). There are a few plants that also perform electrical testing on the winding (i.e., winding resistance and insulation resistance). The only condition-based monitoring that is being used by a few plants are vibration monitoring and thermography.
- Medium voltage motors (2.3 kV – 15 kV) are maintaining an acceptable level of reliability by electrical testing of the windings, vibration monitoring, temperature monitoring, oil analysis and re-greasing activities, as well as scheduled and condition-based refurbishments, and winding replacement.
- Scheduled refurbishments as well as winding replacements in the last 20 years have played a major role in medium voltage motor reliability.
- The main concern was that if the proactive approach of scheduled and/or condition-based refurbishments and winding replacement were to decrease on the motors that have not been refurbished and rewound then large motor reliability will decrease. A secondary concern was the aging effects on the motors to support plant license renewal. Rotor looseness is an anticipated aging degradation and will have to be addressed to maintain an acceptable level of large motor reliability to support plant long term operation.

2.3 Motor Trends - INPO Consolidated Events Systems (ICES) – 1Q-2011 – 2Q-2016

INPO periodically provides EPRI LEMUG with Motor Trends to support motor program improvements. The latest presentation was provided at the August 2016 EPRI LEMUG meeting and is discussed in this section.

The failures provided in the INPO motor trend evaluation included the following:

- Complete motors including the following components:
- Electrical leads, lugs, cables, and wiring from motor through termination box
- Dedicated lubrication oil systems (e.g., reactor coolant and recirculation pump motors)
- Cooling line connections at motor

The motor related events are listed by motor horsepower, voltage ratings, and the number of events affecting power generation. See breakdown below:

- Less than 100 hp (75 kW)- (typically random wound windings with grease lubricated rolling element bearings) Voltage range <600 Vac.
- 100 – 499 hp (75 – 372 kW) – (can be random or form wound windings for the larger horsepower – bearings may be oil lubricated fluid film bearings in the larger horsepower) Voltage range <600 Vac – 6.9kV.
- 500 hp (373 kW) and higher – (typically form wound windings – bearings may be rolling element with grease or oil lubrication or oil lubricated fluid film bearings). Voltage range 2.3kV – 13.2kV.

Evaluation of the motor failures between 1Q of 2011 and 2Q of 2016 provided an insight to the effectiveness of the motor programs at the nuclear sites. The following are the results of the evaluation:

- Low voltage motors less than 100 HP (75 kW) had the highest failure rate because of the number of small motors installed in the plants as compared to the medium voltage motors.
- Low voltage motor failures had the lease impact on power production.

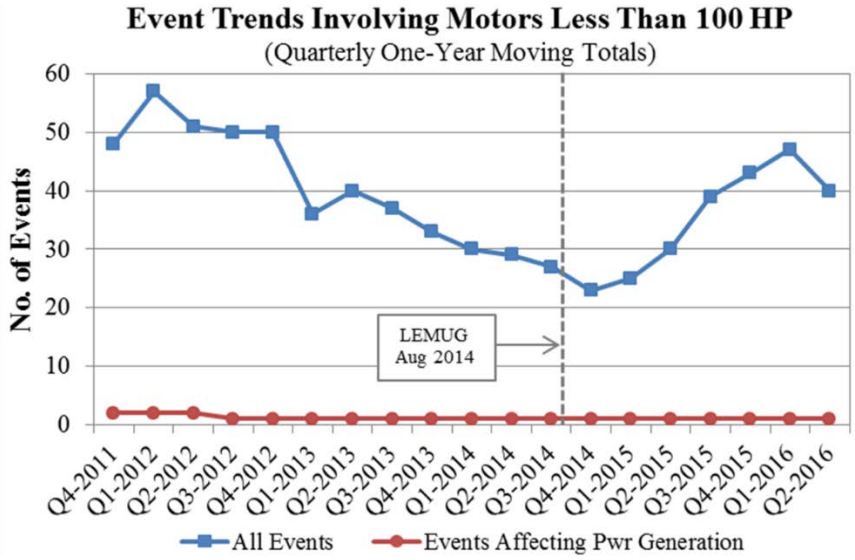


Figure 2-10
Motor Events (<100 HP) and Their Effects on Power Generation

- Motors events (100-499 hp) (75 – 372 kW) have had minimal impact on loss power generation except for 2015. The largest contributor to loss of generation were containment fan cooling failures in Pressurized Water Reactors (PWR).

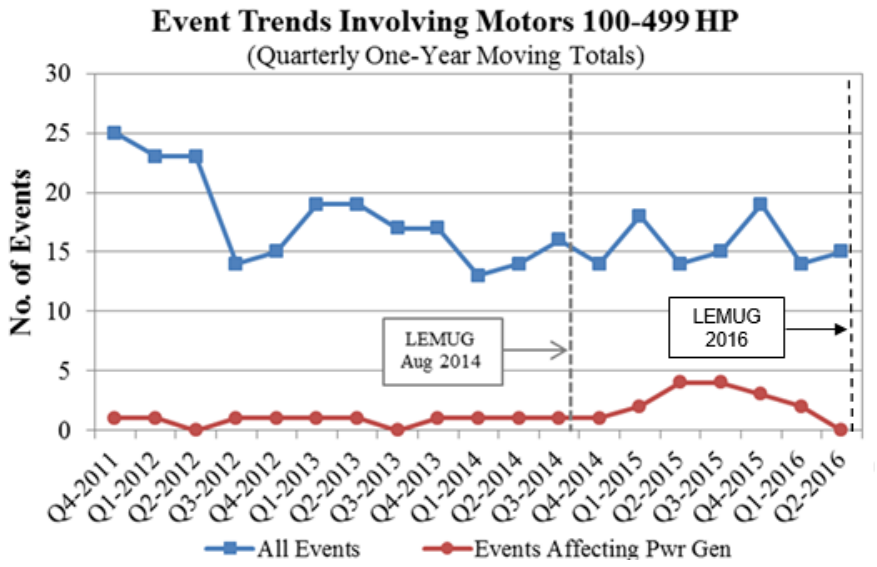


Figure 2-11
100 – 499 HP Motor Events from 1Q-2011 – 2Q-2016

Note: *The uptick in events affecting power generation in 2015 was attributed to containment cooling fan motor failures.*

- Medium voltage motors (2.3 kV – 13.2 kV and above 500 hp (373 kW)) had lower failure rates and have been trending down since 2011 largely due to aggressive maintenance programs which included refurbishments, rewinds, and motor replacement with spares.
- Medium voltage motors (2.3 kV – 13.2 kV and above 500 hp (373 kW)) had the largest impact on power generation. The lost generation has been trending down since 4Q – 2014.

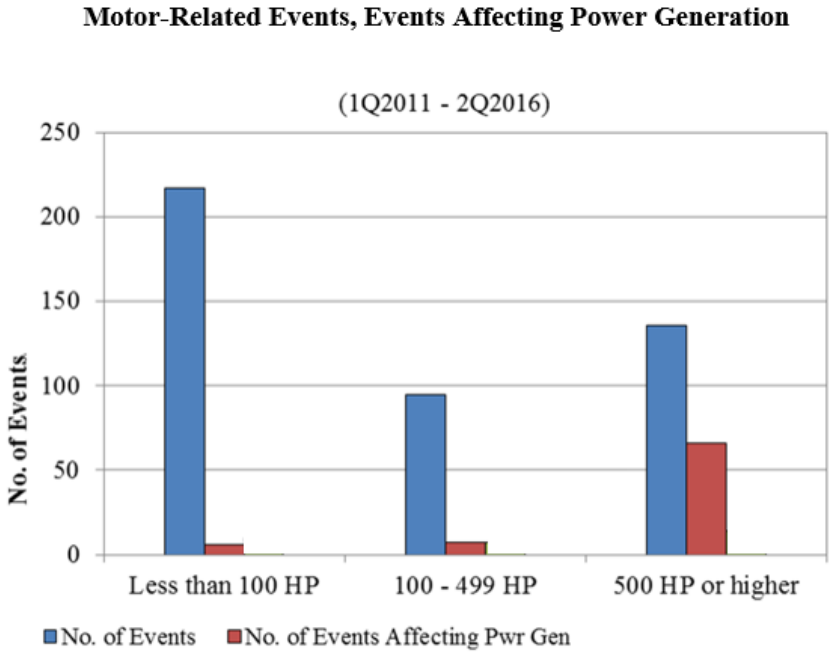


Figure 2-12
All Motor Events - Number of Events Affecting Power Generation

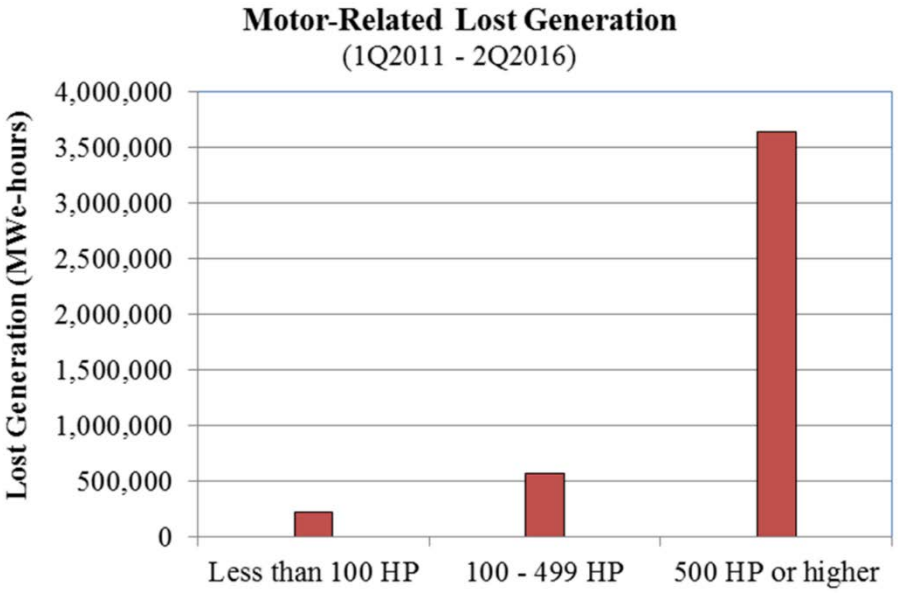


Figure 2-13
Motor Related Lost Generation by Horse Power

- Cooling water motors (i.e., essential service water) greater than 500 hp (393 kW) had the most events but had minimal effect on power generation. This is most likely due to having installed spare motors (i.e., 8 installed motors with only 4 required to operate).
- Condensate pump motors (2.3 kV – 13.2 kV and above 500 hp (393 kW)) had similar failures as reactor coolant and reactor recirculation pump motors with similar impact on loss of power generation. This is most likely due to each condensate motor is rated for 33% of required pump flow with no installed spares. Some plant designs have these motors rated at 50% and could operate at full power with one out of service.
- Reactor recirculation pump motors followed by Reactor coolant pump motors had the most impact on lost generation as most plants cannot operate with one of these motors out of service.

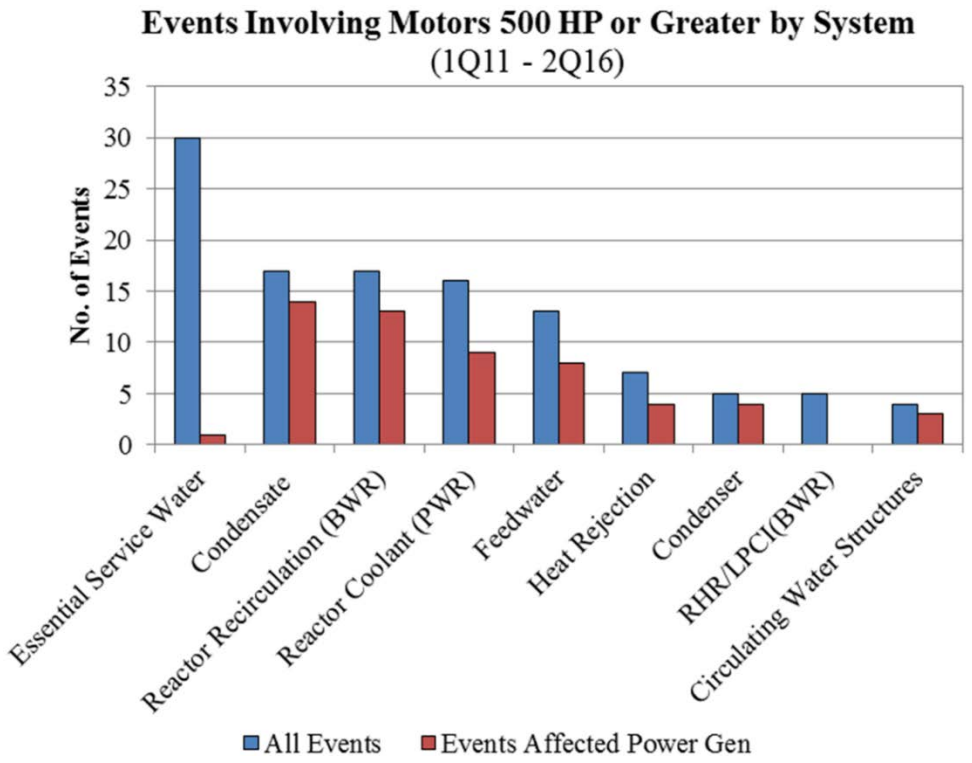


Figure 2-14
Motor Events (500 HP and greater) and Loss Generation by System

Loss of power generation between 1Q- 2011 through 2Q – 2016 were separated into different categories which are listed below in order of most loss generation to least:

1. Auto Scram
2. Power Reduction
3. Manual Scram
4. Shutdown
5. Outage Impact
6. Delayed Power Ascension

Most of the loss of generation were from 1 – 4 listed above.

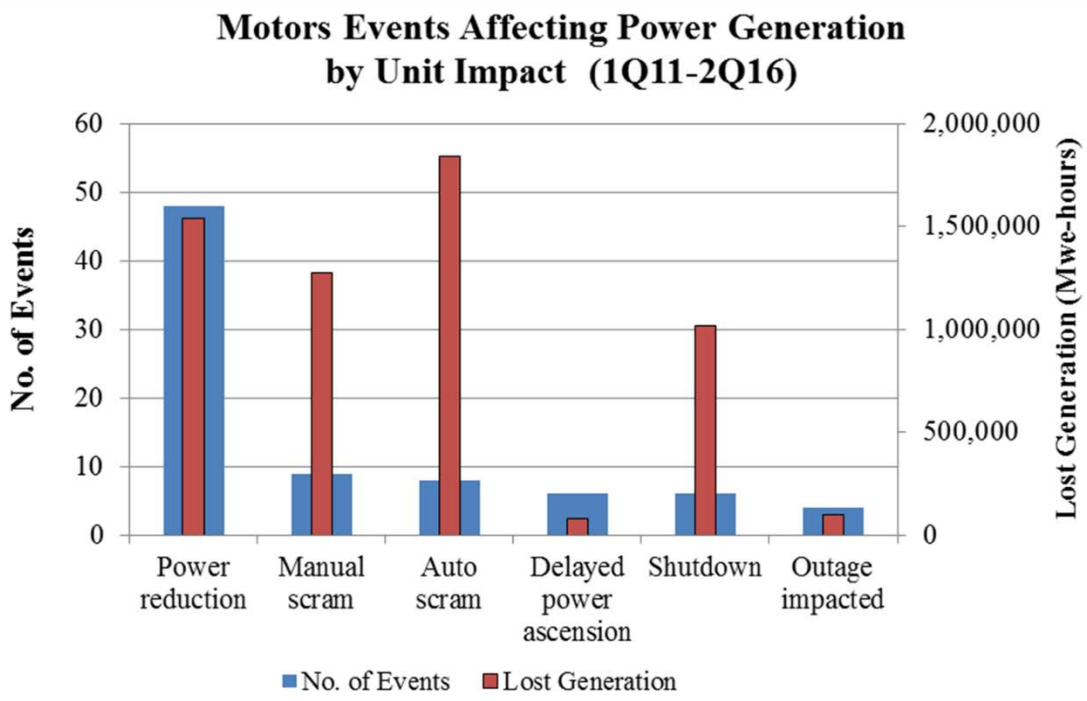


Figure 2-15
Unit Impact of Motor Events (1Q-2011 – 2Q-2016)

The motor data also identified the condition that contributed to the loss of generation. These are discussed in the list below and are listed in order of most loss generation to least:

1. **Fault** – This is a complete loss of the insulation system's dielectric integrity. This type of failure is typically non-recoverable and requires a motor removal, disassembly, and rewind. If the motor is critical to reactor safety or full power operation and a spare motor is not available, then power generation can be affected for a significant amount of time.

   It should be noted that insulation systems that are 30 plus years old have an increased risk of experiencing a fault. This is discussed in more detail in EPRI report 3002000644 [11].

2. **Oil Leaks** – There are many motor designs in each plant. They can be vertical, horizontal, rolling element bearings, fluid film bearings, self-contained oil system, forced fed lubrication system, and contain bearing and/or stator coolers. Oil leaks can occur in oil reservoir seals and gaskets, oil sight glasses, oil sampling and drain plugs, cooling water line penetrations and external oil piping.

   Typically, visual inspections during walk downs can detect oil leaks unless they are internal. Unfortunately, if oil leaks are not detected and corrected, bearing degradation and/or failure can occur.

3. **Bearing Problem** – This can be caused by many issues along with oil leaks as discussed above. Bearing temperature monitoring along with vibration monitoring can detect bearing issues if properly monitored and trended.

4. **High Vibration** – Bearing, alignment, rotor imbalance, soft foot, broken welds, uneven air gap, and several other conditions can cause high vibration. Vibration monitoring can detect this condition if properly monitored. It is important to correct what is causing high vibration or collateral damage can be expected.
5. **Cooler Water Leak** – Internal bearing coolers are typically the most common source of a cooling water leaks.

   Coolers have to be inspected and replaced periodically or wall thinning, corrosion, or joint leaks can leak water into the oil reservoir which can cause bearing degradation and/or failure.

The motor data indicated that faults, bearing failures, and oil leaks were the three main contributors to motor failures and loss of power generation.

If a motor ***has not*** been refurbished since it was installed and it has been in-service for 20 plus years then, consideration should be given for scheduling a refurbishment. This is becoming more of a need with motors life expectancy increasing from 40 years to 60 plus years because of plant license renewal.

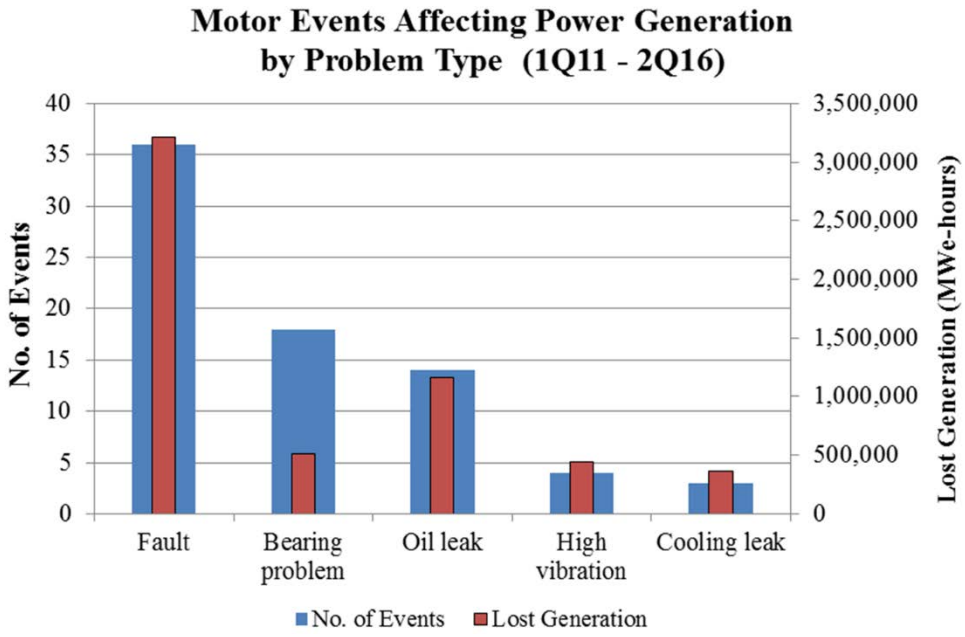


Figure 2-16
Motor Events Affecting Power Generation by Problem Type

Another motor trend that was observed was the motor component failure and how it impacted power generation. The following lists the motor components in order of most failures to least:

Note: *Figure 2-17 shows the impact on power generation from the component failures.*

1. Termination Box (typically a lead lug or connection issue)
2. Bearings
3. Winding/Stator (fault)

4. Oil Cooler Tubes (oil and/or water leak)
5. Oil Pipe Compression Fitting (oil leak)
6. Cooling Fan Shroud (degradation, loose)
7. Oil Pipe (oil leak)
8. Oil Pipe Seal/O-ring (oil leak)

Electrical faults have been a major contributor to loss of power generation and will not improve with age. Insulating materials thermally age and have a thermal life expectancy since they are organic materials. In basic terms, aged insulating materials, operating temperatures, and operational stresses (electrical and mechanical) on the windings have a major role in their capability to perform their intended function. The older and hotter they run, and the more they are started, the shorter their life.

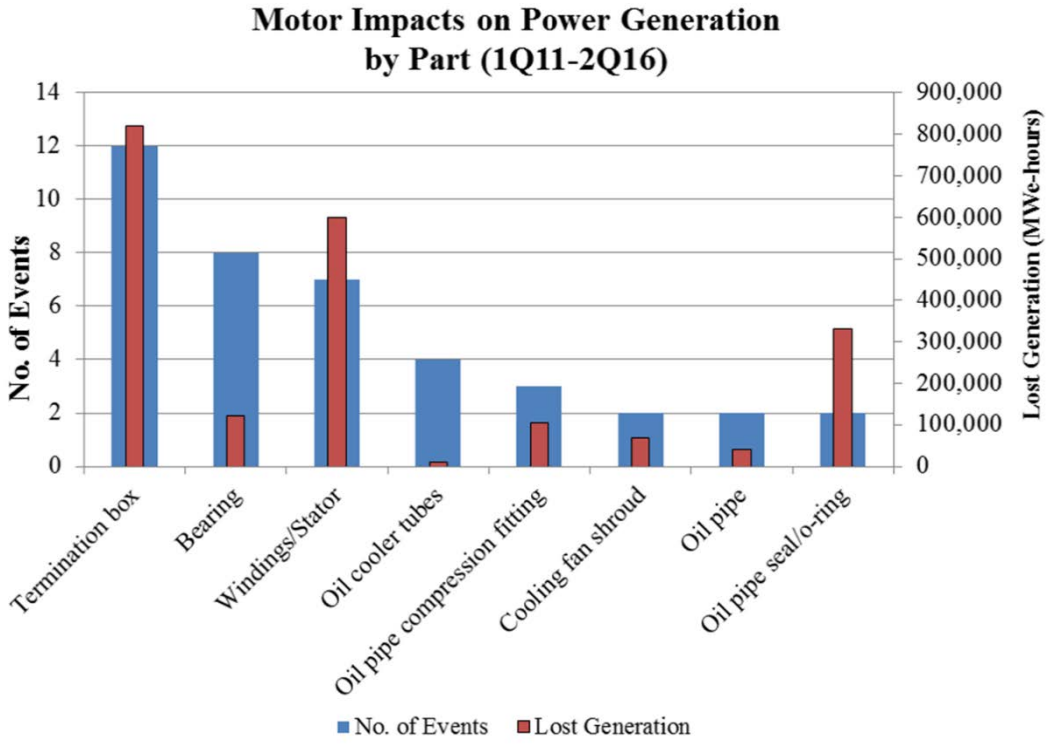


Figure 2-17
Motor Component Failure and its Effect on Power Generation

It should come as no surprise that electrical issues within the junction box, bearing failures, and stator winding failures have a major impact on loss of generation as these failures typically require partial or full disassembly to correct. Some termination box failures can be corrected in the field as with some bearing degradation issues. However, major bearing failure with collateral damage and all winding failures typically require motor removal, complete disassembly, and refurbishment and rewind activities to correct. What was surprising is how oil pipe seals caused a significant loss of generation. These seals (like insulation systems) age and must be replaced periodically.

The motor trend data also had some surprising results for direct causes of the motor events. These are listed below from the most direct cause to the least:

1. **Incorrect reassembly** – This was contributed to preventive maintenance activities which could be from personnel not having enough training on the motor design to vendor quality issues and inadequate work instructions and oversight.

   This trend is easily controlled by having trained personnel performing oversight during refurbishments, having detailed refurbishment specifications, and having the refurbishments performed at a qualified shop that has been properly evaluated.

2. **Aging** – This is becoming more of an issue due to the age of the motors at the time this report was written. Stator and rotor cores, stator windings, bearings, and coolers all experience aging issues.

   This can typically be found and corrected if a proper refurbishment is performed with a thorough as-found condition assessment of all of the motor components.

3. **Stress/Fatigue** – Stress fatigue can be electrical, mechanical, thermal, and/or environmental stresses that a motor is subjected to during its life. Electrical surges, end winding movement during starting, vibration, centrifugal forces on the rotor, torsional forces, and environmental conditions (i.e., hot, corrosive, humid, etc.) can degrade motor components over time.

   Frequent start, high inertia, 3600 rpm, outside, coastal, low temperature location, and humid environment motors will show signs of stress/fatigue at an accelerated rate.

4. **Fouling** – This usually occurs in cooling coils from internal fouling (i.e., corrosion, zebra mussels, etc.) however, air screens and stator and rotor vent ducts can also experience fouling.

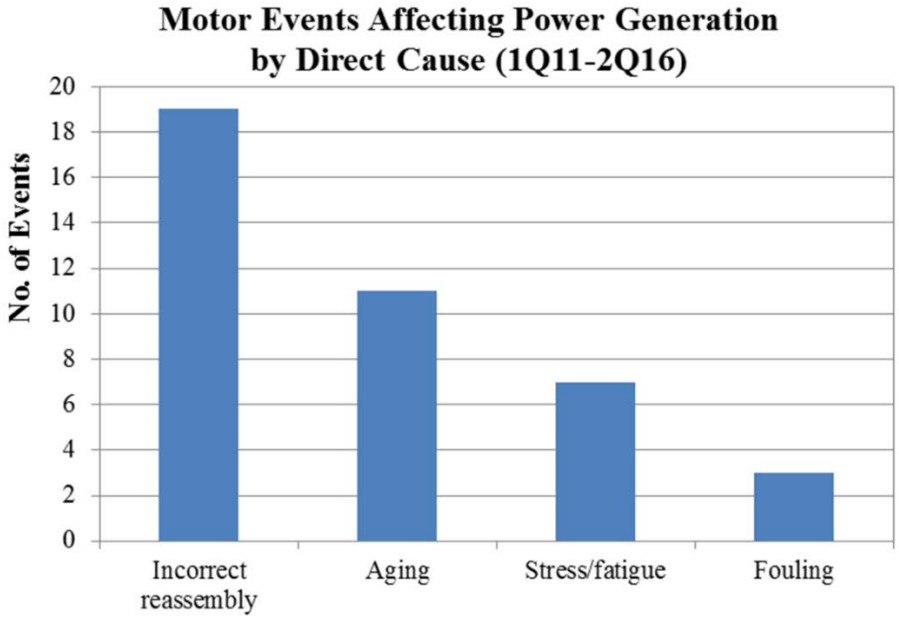


Figure 2-18
Direct Cause of Motor Events Affecting Power Generation

A review of motor failure trends from the INPO data was performed to better understand motor failure causes in nuclear plants and their impact on power generation. The following is a summary of the review:

- Low voltage motors (<100 HP (75 kW)) failures have had minimal impact on power generation.
- 100 – 499 HP (75 -372 kW) motor failures have had little impact on power generation except for containment cooling fan motor failures.
- Many nuclear sites have either replaced, refurbished, and/or rewound many of their medium voltage motors above 500 HP (373 kW). These activities have eliminated many of the degraded conditions and have provided increased motor reliability.
- Motors exposed to the environment (especially those near salt mist and other harsh conditions), 3600 rpm, and high inertia medium voltage motors above 500 HP (373 kW) have had the most failures that have affected power generation.
- Electrical faults, bearing failures, and oil leaks are the main contributors to medium voltage motor failures above 500 HP (373 kW) that affected power generation. However, electrical faults in the terminal box and stator along with bearing failures have been the main contributors to lost generation.
- Aging and stress/fatigue are main contributors to motor failures and typically are a result of not refurbishing motors in a timely manner or degraded conditions were not identified during the motors last refurbishment. Good refurbishment and rewind specifications along with customer oversight of vendor work can address these issues.

3
MINIMUM RECOMMENDATIONS TO MAINTAIN MOTOR RELIABILITY

Review of the industry surveys and discussions with several motor program owners revealed that most of the nuclear plants have developed their motor maintenance programs using the EPRI guidance on motor maintenance as a basis. The recommendations listed in EPRI reports NP-7502 [1], 1003095 [2] and TR-106587 – V8 [3], V9 [4], V10 [5], and V11 [6] (now part of the Preventive Maintenance Basis Database (PMBD) [23]) were foundational in providing guidance for motor maintenance program development.

The common recommendations listed in the EPRI motor maintenance reports are:

- Condition Monitoring PM Tasks
  - Temperature Monitoring
  - Vibration Monitoring
  - Oil Analysis
  - Electrical Tests - On-Line
  - Mechanical Tests - On-Line
  - Electrical Tests - Off-Line
  - Mechanical Tests - Off-Line
- Time and Condition Based PM Tasks
  - External Visual Inspection
  - Partial Disassembly and Inspection
  - Partial refurbishment
  - Refurbishment (includes rewinds)
- Functional Tests
- Recommended Critical Spare Motors

Motor programs that have implemented the afore listed motor maintenance activities have been successful in maintaining motor reliability at an acceptable level and have been a major factor in motor reliability since 2005. Refurbishments of large motors along with stator core restacks and rewinds have also played a significant role in improving motor reliability and will be a major factor in motor reliability for plants that operate 20 plus years beyond original license.

Rotor condition (looseness, broken bars, cracked end rings, etc.) will be a challenge for motor reliability if not addressed during refurbishments. Rotor rebuilds (restacking, rebarring, etc.) are becoming a requirement for many motors due to aging issues. This is discussed in more detail in EPRI reports 3002000644 [11] and 3002005357 [9].

Review of additional motor failure data indicated certain failure trends. Combining these trends with the information contained in the industry surveys summarized in Section 2, minimum effective PMs for each motor category were determined.

When adjustments are made in maintenance activities, there will be a risk impact. Some changes lower risk while others may increase risk. Each motor program owner must understand the impact of changes and understand the associated risk. The vulnerability tool in PMBD was used to access changes recommended in this report. Some examples of these assessments are provided in Appendix B of this report.

3.1 PMs for Low Voltage (<600 Vac) motors (<100 HP (75 kW))

Most low voltage motors are maintaining an acceptable level of motor reliability by performing PM activities on the bearings (i.e., re-greasing and bearing replacement when necessary) and their failures have had minimal impact on power generation.

Industry survey results listed in Section 2 indicates that a good bearing and lubrication program for low voltage motors is significant to maintaining motor reliability. The critical low voltage motors may also have vibration monitoring and thermography performed to allow early detection of bearing issues. Vibration monitoring was listed in the industry surveys as the best predictive maintenance activity for low voltage motors. If electrical testing is required by a plant, then only winding resistance and insulation resistance tests are recommended.

Spare motors are recommended for critical motors that can impact power production (i.e., plant de-rating or shutdown). Obsolete and/or unique low voltage motors should be evaluated for the need of a critical spare as procurement can take a considerable amount of time. EPRI reports 1021428 [17] and 3002010686 [18] provide guidance on NEMA T-frame low voltage motor interchangeability and procurement.

3.2 PMs for Motors of 100 – 499 HP (75 – 372 kW) (Random and Form Wound) (<600V – 6.9kV)

Although there are many 100 – 499 hp (75 -372 kW) motors in power plants, this size of motor is typically simple in design. Horizontal motors of this size are typically squirrel cage induction motors and consist of either rolling element or split sleeve fluid film bearings. In this horsepower range the winding can have either a random or form wound winding design. Motor program owners have indicated that bearing maintenance and lubrication programs are the most important activities associated with these motors. Review of additional industry motor failure data indicated that this size of motor has had minimal impact on plant operation except for containment cooling fan motors. Vibration and temperature monitoring of the bearings are considered the best predictive maintenance for these motors. Electrical testing consisting of winding resistance and insulation resistance (random wound windings) with a polarization index test for form wound windings are the only recommended offline electrical tests for motors of this HP range. These motors can be low voltage (<600 Vac) or medium voltage (2.3kV – 6.9kVac)

motors and partial or full refurbishment will most likely be required for reliable operation for the next 20 plus years if they have not been recently refurbished. Refurbishment including rewinds will most likely be required for the medium voltage motors in this horsepower range if the winding has never been replaced. Stator and rotor cores should be evaluated for continued operation during refurbishments as aging issues will begin to show up as stator and rotor degradation on motors that have been in service 30 plus years.

It is recommended that the need for spare motors be evaluated as some motors in this horsepower range can be manufacturer unique and have long lead times for procurement. If a motor in this horsepower range is considered a critical motor (i.e., failure can cause a plant derating or shutdown) then it is recommended that arrangements for a spare motor be developed.

3.3 PMs for Medium Voltage Motors ≥ 500 HP (≥373 kW) (2.3kV – 6.9kV)

Motors ≥ 500 hp (≥373 kW) are typically medium voltage (2.3kV – 6.9kVac) form wound motors. Nuclear plants that have either replaced, refurbished, and/or rewound these motors have had minimal in-service motor failures. Lubrication and bearing maintenance programs are important for motors of this size to maintain acceptable reliability. Continuous monitoring of bearing and winding temperatures is important for this motor type. Vibration monitoring is also recommended and may be continuous or periodic depending on plant capabilities, assessment of risk, or operational practices. Historically, electrical testing has consisted of winding resistance, insulation resistance, polarization index, and periodic dc step voltage high potential test*. These motors should not exceed 20 years between refurbishments. Large hp motors, high inertia motors, frequent start motors, 3600 rpm motors, and motors exposed to the environment (especially those near salt mist and other harsh conditions) may require more frequent refurbishment. Rewinds are recommended for motors with original windings that have been in continuous operation for 30 plus years. Rewinding at this point in time should minimize in-service failures during the next 20 plus years of operation. Stator cores and rotors should be evaluated for continued operation during refurbishments as aging issues are starting to show stator and rotor degradation on motors that have been in service for more than 30 years.

The need for spare motors should be evaluated as most motors in this horsepower range will have unique designs and long lead times for procurement. If a motor is considered a critical motor (i.e., failure can cause a plant derating or shutdown) then it is recommended that arrangements for a spare motor be developed.

**Very low frequency testing has been investigated as a test for medium voltage cables and motors. See EPRI 3002013161, Field Guide for Very Low Frequency Tan Delta Testing of Medium-Voltage Motors and Cables from the Cable Terminations [19].*

3.4 PMS for Motors ≥ 500 hp (≥373 kW) and > 6.9kV

It is recommended that motors with voltage ratings greater than 6.9kV have online partial discharge testing and/or power factor tip-up tests performed in addition to the recommendations listed in Section 3.3 above because of the potential for partial discharge damage that can occur above this voltage level. See EPRI 1001266 [20] for information on partial discharge testing on rotating machine windings.

Motors in this voltage range are typically reactor coolant pump, reactor recirculation, and large water circulators which are unique in their design. Design attributes for these motors can have additional auxiliaries such as flywheels, lift oil systems, oil and air coolers, and anti-rotation devices.

Most motors of this voltage range can have an impact on power generation if an in-service failure occurs. Degradation of these motors can occur overtime and some degradation can only be detected by internal inspection. Refurbishment of these motors is covered in sections 3.6 and 3.7. For this reason, it is recommended that a spare motor be readily available to allow motor replacement and minimum plant impact in the event of a motor failure. These motors also can take a considerable amount of time to refurbish, repair, and or rewind. Typically, these activities cannot be performed within a typical outage period. A spare motor provides an opportunity for proper refurbishment and/or repair activities to be performed in the event of a motor failure. Also, having a spare motor available limits the time required to bring a plant back into service.

3.5 PMs for Environmentally Qualified (EQ) Motors (Random and Form Wound)

A large amount of EQ motors only operate for surveillance testing and during accident conditions. This means that actual operation time on these motors will be less than those that are required to operate continuously. Also, many of these motors are in a protected plant environment (not including accident conditions) minimizing thermal aging and environmental degradation. Because these motors are considered EQ, one would think that maintenance on these motors would require more extensive programs. However, bearing lubrication and maintenance programs are the most important followed by vibration and temperature monitoring to detect early bearing and/or winding degradation. Periodic offline electrical testing is recommended to ensure that the dielectric strength of the winding is sufficient for continued operation.

It is important to understand that EQ motors may have requirements of condition monitoring, testing, and end of qualified life issues that will have to be addressed separately from recommendations provided in this report.

Table 3-1 provides recommendations on the ***Minimum Activities to Maintain Motor Reliability*** for the different motor types discussed in Sections 3.1 – 3.5. These activities should be considered as minimum recommended maintenance to maintain an acceptable level of motor reliability to support plant license renewal that may require 60 plus years of operation.

See Table 3-2 for recommendation on refurbishments.

Table 3-1
Recommended Minimum Activities for Motor Maintenance

Motor Type	Minimum Activities for Maintenance	Recommend Spare Motor	Comments
Low Voltage Motors (<600V) (<100 HP) (<75 kW)	Lubrication (re-greasing) Bearing replacement* Vibration monitoring on critical motors. ***Note:** Opportunity to inspect and test motor when bearing replacement is performed since motor is disassembled.	Recommended spare for critical motors. Critical motors are those that can cause a plant de-rating or shutdown.	The majority of low voltage motors installed in nuclear plants are squirrel cage induction motors with random wound windings and grease lubricated rolling element bearings. Industrial grade (i.e., cast-iron housings) are inherently considered to be rugged in their design and typically have very few problems except for bearing degradation from time in service (i.e., L10 life) or poor lubrication programs.
Low and/or Medium Voltage Motors (100 - 499 HP) (75 – 372 kW) Random and Form Wound (<600 V – 6.9 kVac)	Lubrication (re-greasing or oil analysis depending on bearing design) Vibration and temperature monitoring on critical motors that can cause plant de-ratings or shutdown. Winding resistance, insulation resistance and polarization index test on form wound windings of critical motors. Bearing inspections if condition monitoring indicates degradation. Note: Opportunity to inspect and test motor when bearing inspection and/or replacement is performed.	Recommend evaluating the need for a spare motor especially if a motor is considered critical. Critical motors are those that can cause a plant de-rating or shutdown.	Motors of this size can be low voltage or medium voltage, random or form wound windings, grease or oil lubricated rolling element bearings or oil lubricated fluid film bearings and cast aluminum or copper fabricated rotors. Failure data discussed in Section 2 has indicated that motors of this size have the least impact on power generation. However, there are critical motors that fall in this range of HP and should have all of the recommended maintenance performed as listed in the column of this table labeled Minimum Activities for Maintenance.

Table 3-1 (continued)
Recommended Minimum Activities for Motor Maintenance

Motor Type	Minimum Activities for Maintenance	Recommend Spare Motor	Comments
Medium Voltage Motors (≥500 HP) (≥373 kW) (2.3 kV – 6.9 kVac)	Lubrication (re-greasing or oil analysis depending on bearing design) Vibration and temperature monitoring. Winding resistance, insulation resistance and polarization index test, dc step voltage test+ +*Very Low Frequency Testing can be used in lieu of dc step test* Online current analysis should be performed as required to base line, validate, or trouble shoot performance issues See Table 3-2 for refurbishment recommendations	Recommend spare for critical motors. Critical motors are those that can cause a plant de-rating or shutdown.	These designs can vary in complexity and may include oil and/or air coolers, thrust bearings, bearing insulation, motor heaters, and anti-rotation devices. They can be solid or hollow shaft, horizontal or vertical, and range from low rpm to 3600 rpm. These motors may be located inside a plant or outside in a harsh environment (i.e., salt mist). The majority will be squirrel cage induction motors but there are some synchronous motors included in this category. All of these design attributes have to be evaluated to determine what level of maintenance activities should be performed and the frequency of refurbishments as some design attributes and operational requirements stress motor components more than others.
Medium Voltage Motors (≥500 HP) (≥373 kW) (> 6.9 kVac)	All recommended minimum activities for maintenance listed under Medium Voltage Motors (≥ 500 HP) (2.3kV – 6.9kV) listed above apply to motors ≥ 500 HP with voltage ratings greater than 6.9kV In addition, partial discharge and/or power factor tip-up tests are also recommended because of the damaging effects of partial discharge to insulating materials and other materials internal to the motor from ozone generated by the partial discharge. See Table 3-2 for refurbishment recommendations	A spare is recommended for each family of these motors because failures typically affect power generation. Also, procurement of a spare for motor of this size and voltage usually takes a considerable amount of time (i.e., 6 – 12 months or greater).	Motors ≥ 500 HP and > 6.9kV are typically reactor coolant pump, reactor recirculation, or large water circulators and can have additional auxiliaries (i.e., flywheel, lift oil system, anti-rotation device, oil and air coolers, etc.). Refurbishments, rewinds, stator core and rotor replacements, lift oil system component replacement, and cooler testing and/or replacement are not uncommon maintenance activities to provide the level of reliability that these motors require. Rotor degradation can occur on motors of this size after extended time in service (i.e., between 20 to 30 years). Refurbishment is an opportunity to apply repairs to avoid rotor failure [9].

Table 3-1 (continued)
Recommended Minimum Activities for Motor Maintenance

Motor Type	Minimum Activities for Maintenance	Recommend Spare Motor	Comments
EQ Motors	Maintenance activities for EQ motors consist of a good lubrication and bearing maintenance program. For the larger EQ motors, recommend vibration and temperature monitoring of the bearings, temperature monitoring of the windings if embedded temperature elements are installed as well as offline electrical tests for the windings. [+] [+]*Very Low Frequency Testing can be used in lieu of dc step test.*	EQ motors should have a spare as they cannot be easily obtained or repaired in a timely manner.	EQ motors have required maintenance in EQ documents (i.e., EQ binders) that establishes the EQ requirements for each motor. The EQ maintenance requirements take precedence over any recommendations listed in this report. The EQ maintenance requirements are reflected in the motor maintenance program for EQ motors. ***Remember, you can always perform more maintenance than the EQ required maintenance, but you have to revise the EQ binders for a motor if you want to perform less maintenance than the EQ required maintenance.***

General Information for Table 3-1

- The minimum activities for motor maintenance are considered the ***minimum*** maintenance activities that should always be a part of a motor maintenance program.
- This does not mean that other maintenance activities are not useful. As an example, online electrical testing is very useful for verifying motor performance and can find rotor bar cracks and rotor eccentricity. If this technology is used to baseline a motor and then periodically performed, changes in motor performance can be trended.
- Refurbishments are not included in Table 3-1 as they are discussed in Table 3-2.
- Table 3-1 are ***recommendations*** based on industry survey results pertaining to individual plants motor programs, INPO motor failure trend data, and discussions with motor engineers during LEMUG meetings and independent phone conversations.

3.6 The Need for Motor Refurbishment

Table 3-1 provides recommendations for the minimum activities for motor maintenance to maintain an acceptable level of motor reliability. However, testing and condition monitoring (see Section 4 for condition monitoring) alone will not be able to find all degradation that a motor may experience over its operational life; therefore; refurbishments are included as an activity on many of the motors listed in Table 3-2.

Implementing the maintenance activities listed in Table 3-1 should provide short term reliability for most motors. However, critical motors 100 – 499 HP (75 – 372 kW) and all motors $\geq$ 500 HP (373 kW) typically will require partial or full refurbishments to provide the level of reliability needed to minimize in-service failures to support plant license renewal. Refurbishments are recommended because many degraded conditions can only be found during inspections by trained personnel after motor disassembly. Many of these conditions can cause in-service failures or even catastrophic failures. The bullet list below are examples of some of the degraded conditions that can only be found during refurbishment inspections. This list is not all inclusive.

- Loose windings, end-bracing, or wedges
- Brittle or damaged insulation *(physical damage, not dielectric damage)*
- Dirty and/or oily windings *(unless it affects winding temperature)*
- Surge ring damage or looseness
- Finger and vent slot looseness
  - Stator
  - Rotor
- Lamination degradation (separation, corrosion, stack migration, hot spot, or lamination collapse at vent slots, etc.)
  - Stator
  - Rotor
- Stator frame and stator core weld cracks

- Rotor welds
- Scratched or damaged journals *(RMS finish not acceptable)*
- Beginning stages of Babbitt damage on guide or thrust bearings
- Embedded particles and static charge damage to bearings
- Damaged or degraded bearing insulation
- Rotor bar or shorting ring damage or hardware looseness *(Online current analysis can detect rotor bar and shorting ring damage if there is a break in the electrical circuit – (i.e., complete broken rotor bar)*
- Internal motor lead insulation degradation *(this is becoming a major problem on motors that are 25 years or older)*
- Foreign material internal to the motor

Limited internal inspections on some motor designs can be achieved by the use of a flexible borescope. Although a borescope inspection does not provide the same degree of internal inspection that can be seen during a disassembly, it can detect some indications of rotor and winding problems that need immediate attention.

In order to achieve a successful refurbishment, it is recommended that plants consider the following guidance:

- A detailed refurbishment specification is developed by the customer and implemented by the vendor. EPRI has published refurbishment specifications for low voltage [8], medium voltage [7], and DC motors [21]. These EPRI reports provide a basis for developing individual plant motor refurbishment specifications.
- A quality service shop should be used to refurbish nuclear plant motors. A shop that is familiar with nuclear equipment requirements, has the proper QA program, performs most of the refurbishment activities in-house, has an experienced refurbishment crew, and takes limited exceptions to the customers refurbishment specification that can affect quality is recommended. (*Note: There will always be some exceptions taken but not all exceptions taken by a shop will affect quality*).
- Customer involvement and oversight is recommended during critical activities throughout the entire refurbishment process to ensure that the activities are in accordance with the refurbishment specification and that all anomalies are identified and addressed before motor assembly. This requires a trained individual to perform the oversight that is familiar with both the electrical and mechanical design attributes of motors.

Failure to implement the recommendations listed above may result in refurbishment and/or assembly issues that may lead to operational issues or even motor failure.

3.7 Motor Refurbishment Recommendations

During the develop of this report is was determined to provide recommendations for future motor refurbishments deemed necessary to provide an acceptable level of reliability to support the next 20 plus years of operation.

Table 3-2 provides recommendations for refurbishments based on the present condition of each motor type. Future refurbishments, rewinds, stator core restacks, and rotor replacement activities are based on past refurbishments, rewinds, stator core restacks, and rotor replacements that have been completed and/or known degraded conditions.

Table 3-2
Recommendations on Motor Refurbishment, Rewind, Stator Core, and Rotor Replacement

Motor Type	Original Windings, Stator Core, and Rotor	Winding has been Replaced Original Stator Core and Rotor	Winding and Stator Core have been Replaced Original Rotor	Winding, Stator Core and Rotor have been Replaced
Low Voltage Motors (<600V) (<100 HP) (<75 kW)	If motor has been in-service for 30 plus years with only bearing maintenance, a replacement motor should be considered unless the motor is unique or obsolete. Bearing and lubrication maintenance is required to maintain reliability to achieve maximum life for these motors.	If the winding has been replaced within the last 10 years (stator core and rotor were in good condition), bearing maintenance only is recommended unless a degraded condition is detected	If the winding and stator core have been replaced within the last 10 years (rotor was in good condition), bearing maintenance only is recommended unless a degraded condition is detected.	Bearing and lubrication maintenance is required to maintain reliability to achieve maximum life for these motors.
Low and/or Medium Voltage Motors (100 - 499 HP) (75 – 372kW) Random and Form Wound (<600 V – 6.9 kVac)	If motor has been in service for 30 plus years, a refurbishment is recommended to evaluate winding, stator core, and rotor condition. Assumes bearing maintenance has been performed. Winding, stator core, and/or rotor may require replacement to ensure reliable operation for 20 plus years.	If winding has been replaced within the last 10 years, recommend scheduling a refurbishment not to exceed 20 years to evaluate the stator core and rotor for continue service. Assumes stator core, and rotor inspections were performed at time of last refurbishment. Assumes fluid film bearings were dimensionally checked and inspected and rolling element bearings were replaced at last refurbishment	If winding and stator core have been replaced in the last 10 years, recommend scheduling a refurbishment not to exceed 20 years to evaluate the rotor for continue service. Assumes rotor inspections were performed at time of last refurbishment. Assumes fluid film bearings were dimensionally checked and inspected and rolling element bearings were replaced at last refurbishment	If winding, stator core, and rotor have been replaced in the last 10 years, recommend scheduling partial refurbishment not to exceed 20 years. Assumes bearing conditions are monitored to detect degradation. Assumes fluid film bearings were dimensionally checked and inspected and rolling element bearings were replaced at last refurbishment

Table 3-2 (continued)
Recommendations on Motor Refurbishment, Rewind, Stator Core, and Rotor Replacement

Motor Type	Original Windings, Stator Core, and Rotor	Winding has been Replaced Original Stator Core and Rotor	Winding and Stator Core have been Replaced Original Rotor	Winding, Stator Core and Rotor have been Replaced
Medium Voltage Motors (≥500 HP) (≥373 kW) (2.3 kV – 6.9 kVac)	If motor has been in service for 30 plus years, recommend scheduling a complete refurbishment with rewind. Evaluate the stator core and rotor for continued service. Stator core and/or rotor may require replacement to ensure reliable operation for 20 plus years.	If winding has been replaced within the last 10 years, recommend scheduling a refurbishment not to exceed 20 years to evaluate the stator core and rotor for continue service. Assumes stator core, and rotor inspections were performed at time of last refurbishment. Assumes oil and/or air coolers were inspected, tested, and/or replaced at last refurbishment. Assumes fluid film bearings were dimensionally checked and inspected and rolling element bearings were replaced at last refurbishment	If winding and stator core have been replaced in the last 10 years, recommend scheduling a refurbishment not to exceed 20 years to evaluate the rotor for continue service. Assumes rotor inspections were performed at time of last refurbishment. Assumes oil and/or air coolers were inspected, tested, and/or replaced at last refurbishment. Assumes fluid film bearings were dimensionally checked and inspected and rolling element bearings were replaced at last refurbishment	If winding, stator core, and rotor have been replaced in the last 10 years, recommend scheduling partial refurbishment not to exceed 20 years. Assumes bearing conditions are monitored to detect degradation. Assumes oil and/or air coolers were inspected, tested, and/or replaced at last refurbishment. Assumes fluid film bearings were dimensionally checked and inspected and rolling element bearings were replaced at last refurbishment

Table 3-2 (continued)
Recommendations on Motor Refurbishment, Rewind, Stator Core, and Rotor Replacement

Motor Type	Original Windings, Stator Core, and Rotor	Winding has been Replaced Original Stator Core and Rotor	Winding and Stator Core have been Replaced Original Rotor	Winding, Stator Core and Rotor have been Replaced
Medium Voltage Motors (≥500 HP) (≥ 373 kW) (>6.9 kVac)	If motor has been in service for 30 plus years, recommend scheduling a complete refurbishment with rewind. Evaluate the stator core and rotor for continued service. Stator core and/or rotor may require replacement to ensure reliable operation for 20 plus years. Oil and/or air coolers along with auxiliary equipment (i.e., lift oil system components, anti-rotation devices, etc.) may require refurbishment and/or replacement.	If winding has been replaced within the last 10 years, recommend scheduling a refurbishment not to exceed 20 years to evaluate the stator core and rotor for continue service. Assumes oil and/or air coolers were inspected, tested, and/or replaced at last refurbishment. Assumes auxiliary equipment (i.e., lift oil system components, anti-rotation devices, etc.) were inspected and/or replaced at last refurbishment. Assumes fluid-film bearing were dimensionally checked and inspected during last refurbishment. Assumes stator core and rotor inspections were performed at last refurbishment. **Note:** For motors that have been in-service for 40 plus years, stator core and rotor should be inspected for possible replacement during refurbishment.	If winding and stator core have been replaced in the last 10 years, recommend scheduling a refurbishment not to exceed 20 years to evaluate the rotor for continue service. Assumes oil and/or air coolers were inspected, tested, and/or replaced at last refurbishment. Assumes auxiliary equipment (i.e., lift oil system components, anti-rotation devices, etc.) were inspected and/or replaced at last refurbishment. Assumes fluid-film bearing were dimensionally checked and inspected during last refurbishment. Assumes rotor inspections were performed at last refurbishment. **Note:** For motors that have been in-service for 40 plus years, rotor should be inspected for possible replacement during refurbishment.	If winding, stator core, and rotor have been replaced in the last 10 years, recommend scheduling partial refurbishment not to exceed 20 years. Assumes bearing conditions are monitored to detect degradation. Assumes oil and/or air coolers were inspected, tested, and/or replaced at last refurbishment. Assumes auxiliary equipment (i.e., lift oil system components, anti-rotation devices, etc.) were inspected and/or replaced at last refurbishment. Assumes fluid-film bearings were dimensionally checked and inspected at last refurbishment.

Table 3-2 (continued)
Recommendations on Motor Refurbishment, Rewind, Stator Core, and Rotor Replacement

Motor Type	Original Windings, Stator Core, and Rotor	Winding has been Replaced Original Stator Core and Rotor	Winding and Stator Core have been Replaced Original Rotor	Winding, Stator Core and Rotor have been Replaced
EQ Motors	If motor has reached end of qualified life, the following options are available: • Extend Qualified life by using actual plant environmental data to determine how much thermal life has been removed from a motor • Rewind stator ***Note:*** *An EQ winding must be evaluated and approved prior to rewinding an EQ motor.* • Replace motor with qualified EQ motor. Refurbishments should be based on EQ requirements (i.e., L10 life for bearing replacement) and degradation determined from condition monitoring (i.e., dielectric test anomaly, babbitt particles in oil analysis, etc.)	Winding replacement will reset qualified life of motor. Assumes stator core and rotor inspections were performed at last refurbishment. Perform maintenance as Required by the EQ documentation (i.e., EQ Binders) to maintain motor's EQ requirements. Refurbishments should be based on EQ requirements (i.e., L10 life for bearing replacement) and degradation determined from condition monitoring (i.e., dielectric test anomaly, babbitt particles in oil analysis, etc.)	Winding replacement will reset qualified life of motor. Assumes stator core was replaced due to degradation identified before winding replacement. Assumes rotor inspection was performed at last refurbishment Perform maintenance as Required by the EQ documentation (i.e., EQ Binders) to maintain motor's EQ requirements. Refurbishments should be based on EQ requirements (i.e., L10 life for bearing replacement) and degradation determined from condition monitoring (i.e., dielectric test anomaly, babbitt particles in oil analysis, etc.)	Perform maintenance as required by the EQ documentation (i.e., EQ Binders) to maintain motor's EQ requirements. Refurbishments should be based on EQ requirements (i.e., L10 life for bearing replacement) and degradation determined from condition monitoring (i.e., dielectric test anomaly, babbitt particles in oil analysis, etc.).

Notes for Table 3-2:

Some motors experience more degradation from operational and environmental stresses. The following motors may require more frequent refurbishment activities than listed in Table 3-2 because of these increase stresses:

1. Motors located outside (subject to dirt, humidity, rain, salt mist, and snow)
2. 3600 rpm motors (subject to significant increase in centrifugal forces on the rotor)
3. High inertia motors (subject to long acceleration times which places thermal stresses on the rotor and mechanical stresses in the end windings)
4. Frequent start motors (subject to starting stresses which consists of thermal stresses on the rotor, mechanical stresses on the stator end windings, and electrical stresses from voltage spikes generated by closing and opening the breaker).
5. Use [22] for guidance on repair verses replacement to determine cost benefit for motor refurbishment. If these motors meet the replacement criteria, it is recommended ***replacing*** motors with new as needed. The exception may be for motors that are unique (includes EQ) or obsolete. These motors may be more beneficial to refurbish due to the difficulty and expense in obtaining a replacement.

All of these stresses stated above have a degrading effect on a motor and must be taken into consideration when determining how often a motor should be scheduled for a refurbishment.

Note: *Standby motors that are not affected by environmental stresses may have their recommended refurbishment frequencies adjusted if condition monitoring is performed (i.e., temperature and vibration monitoring, oil analysis, etc.) to allow early detection of degraded conditions.*

4
MOTOR MONITORING

Motor reliability can only be achieved by implementing different program elements that make up an effective motor program. However, motor design (i.e., low voltage, medium voltage, horsepower range, orientation (horizontal, vertical), etc.) and the critical nature of the motor as it pertains to plant power generation (i.e., deratings and unit shutdown) play a major role in which predictive and preventive maintenance activities maintain an acceptable level of reliability [2].

This section provides guidance on periodic and continuous condition monitoring that may be added (if not already in use) to existing motors or installed on new motors being procured. Different condition monitoring is recommended for different motors in Table 4-1 to reflect minimum monitoring recommendations for the different categories of motors. More monitoring may be added based on individual plant needs and/or requirements.

Walkdown inspections are a useful monitoring tool to detect visible and auditable indications of electric motor degradation. Results of these inspections should be documented for review.

4.1 Periodic and Continuous Monitoring

The most common condition monitoring techniques for motors are bearing vibration and temperature and winding temperatures. Motors with oil lubricated bearings should have oil level and oil quality monitoring.

There are other monitoring technologies that are useful on motors to determine changes in their operational performance either from the motor or the driven equipment. Other tests may require physical test lead connections inside the breaker relay compartment. Some plants have installed external plug-in ports to the motor supply breaker compartment to reduce the risk of personnel error during hookup and removal of the test leads. External plug-in ports make testing simpler without the need for arc flash clothing.

Table 4-1 provides minimum periodic and continuous monitoring recommendations for the different types of motors installed in power plants.

Table 4-1
Minimum Recommended Periodic and Continuous Monitoring for Motors

Motor Type	Periodic Monitoring	Continuous Monitoring	Comments
Low Voltage Motors (<600V) (<100 HP) (<75 kW)	**Non-Critical Motors** Low voltage motors with grease lubricated bearings do not require periodic monitoring unless needed for troubleshooting. **Critical Motors** Critical low voltage motors should have periodic vibration and temperature monitoring performed on the bearings as well as monitoring current to determine changes in performance.	**Non-Critical and Critical Motors** No Recommendations	The majority of low voltage motors installed in nuclear plants are squirrel cage induction motors with random wound windings and grease lubricated rolling element bearings. Industrial grade (i.e., cast iron housings) are considered to be inherently rugged in their design and typically have very few problems except for bearing degradation from time in service (i.e., L10 life) or poor lubrication programs. Since induction motors are load followers, changes in current draw are typically a result of increased load demand or mechanical binding within the motor or driven equipment.
Low and Medium Voltage Motors (100 - 499 HP) (75-372 kW) Random and Form Wound (<600V – 6.9 kVac)	**Non-Critical Motors** Low voltage (<600 Vac) random wound motors with grease lubricated rolling element bearings should have periodic bearing vibration and temperature monitoring performed. For 4 – 6.9 kV form wound motors with oil lubricated bearings, oil analysis and oil level verification should also be a part of periodic monitoring. **Critical Motors** In addition to non-critical periodic monitoring, periodic online electrical testing for baseline and troubleshooting is recommended.	**Non-Critical Motors** No Recommendations **Critical Motors** Continuous monitoring of bearing temperatures is recommended.	Motors of this size can be low voltage or medium voltage motors, random or form wound windings, grease or oil lubricated rolling element bearings or oil lubricated fluid film bearings and cast aluminum or copper fabricated rotors. Failure data discussed in Section 2 has indicated that motors of this size have the least impact on power generation; however, there are critical motors that fall into this HP range.

Table 4-1 (continued)
Minimum Recommended Periodic and Continuous Monitoring for Motors

Motor Type	Periodic Monitoring	Continuous Monitoring	Comments
Medium Voltage Motors (≥500 HP) (≥ 373 kW) (2.3 kV – 6.9k Vac)	**Non-Critical Motors** Periodic bearing vibration and temperature monitoring is recommended. A lubrication program (depending on bearing design) consisting of re-greasing, oil analysis, oil level verification, and oil change is recommended. **Critical Motors** In addition to the non-critical periodic monitoring, periodic online electrical testing for baseline and troubleshooting is recommended.	**Non-Critical Motors** No Recommendations **Critical Motors** Continuous monitoring of bearing temperatures and vibration is recommended. Continuous monitoring of winding temperature is recommended.	Auxiliary equipment for these motors may include oil and/or air coolers, thrust bearings, bearing insulation, motor heaters, and anti-rotation devices. Some motors in this voltage and horsepower range will be synchronous and may be located in a harsh environment (i.e., salt mist). Critical motors of this voltage and horsepower will impact power generation if they fail. This is based on the motor trend results from industry data discussed in Section 2.
Medium Voltage Motors (≥500 HP) (≥373 kW) (>6.9 kVac)	Oil analysis and oil changes are recommended periodically. Periodic oil level verification is recommended if continuous monitoring is not available. For totally enclosed water to air cooled motors of this voltage range, periodic partial discharge and ozone monitoring should also be considered.	Almost all motors of this voltage range are important to plant operation and power generation, therefore the following continuous monitoring is recommended: • Bearing temperature • Bearing Vibration • Shaft Vibration • Winding Temperature • Oil Level	Motors in this voltage and horsepower range typically support reactor coolant pumps, reactor recirculation pumps, or large water circulators and can have additional auxiliary equipment in their design (i.e., flywheel, lift oil system, anti-rotation device, oil and air coolers, etc.). It is important to monitor the performance of these motors continuously as removal and repair can be costly and failure of one of these motors may cause the plant to run in a derated condition or may cause a unit shutdown for an extended period of time if a spare motor is not available.

Table 4-1 (continued)
Minimum Recommended Periodic and Continuous Monitoring for Motors

Motor Type	Periodic Monitoring	Continuous Monitoring	Comments
EQ Motors	**EQ motors** have essential EQ maintenance requirements which must be followed. In addition, EQ motors ≥100 HP have, as a minimum, the same periodic monitoring recommendations as the critical motors in this table under the appropriate motor category.	**EQ motors ≥500 HP (373 kW)** should have as a minimum the following continuous monitoring: • Bearing temperature • Bearing Vibration • Winding Temperature	It should be noted that EQ motors typically have required maintenance in the EQ documentation (i.e., EQ binders). The EQ maintenance requirements take precedence over any recommendations listed in this report. The EQ maintenance requirements should be reflected in the motor maintenance program for EQ motors.

5
CONCLUSIONS

Any changes to maintenance programs that affect equipment reliability should be evaluated thoroughly by those most familiar with the equipment.

Maintenance program adjustments can be made without impacting equipment performance; however, some changes can affect performance, missed opportunities for collecting trending data, and lead to premature equipment failure.

The following items should be considered before making adjustments to a motor maintenance program:

- **Motor Design attributes**
  - Bearing types
  - Bearing configuration
  - Anti-rotation device
  - Flywheel
  - Winding design
    - Random wound
    - Form wound
    - Insulation class
  - Lubrication requirements
    - Oil
      - Mineral oil
      - Synthetic
    - Grease
      - Grease type (i.e., lithium, poly-urea gel, synthetic, etc.)
  - Cooler requirements
    - Air
    - Oil
  - Motor heater requirements
  - Nameplate information

  - Installed temperature elements
    - Bearing
    - Winding
  - Installed sensors
    - Accelerometers
    - Proximately probes
    - Oil level transmitters
- **History of the motor**
  - Years in operation
  - Past failures
  - Past repairs (i.e., bearing replacement, stator core restack, new winding, etc.)
  - Past maintenance activities
- **Operational requirements**
  - Continuous operation
  - Intermittent
  - Frequent start
  - Functional requirement of Online spare
  - Motor is only required to operate during accident conditions and surveillance
- **System design attributes**
  - High inertia start motor
  - Starts against reverse flow
  - Motors powered by drives
- **Environmental conditions**
  - Inside motor
    - Mild environment
    - Corrosive environment (i.e., boron, etc.)
    - High temperature location (i.e., ambient temperatures above 110°F (43.3°C))
    - High humidity environment (i.e., steam leaks)
    - High radiation environment
  - Outside motor
    - Corrosive environment (i.e., salt mist, etc.)
    - Damp environment (i.e., near lakes, rivers, or cooling towers)

  - Particulate contaminated environment (i.e., sand blown by wind)
  - High temperature location (i.e., ambient temperatures above 110°F (43.3°C))

- **Motor's failure effect on unit operation**
  - Will failure of motor cause a unit derating?
  - Will failure of motor cause a unit shutdown?
- **Spare motor availability**
  - Is there an installed spare?
  - Is there an available spare properly maintained in a warehouse?

Knowledge of each of the items listed in the bullet list above will assist in justifying any changes to motor maintenance or maintaining the existing motor maintenance program.

Motor maintenance is costly, uses valuable resources, and may affect outage schedules. Therefore, it is logical that reduction of motor maintenance reduces costs. However, making changes to motor maintenance based solely on cost reduction and not considering the impact on motor reliability could be counterproductive. In addition, not all motors require the same level of maintenance to maintain an acceptable level of reliability. This is discussed in the EPRI Tiered Motor Maintenance Program [2].

In 2018, EPRI LEMUG recognized the challenges of maintaining motors to support plant license renewal to operate for 20 plus additional years over the original designed 40 years of operation as well as the cost reduction initiative in the nuclear power industry. The items in the list below were used to develop the recommended maintenance activities provided in this report:

- Industry survey results on motor maintenance (Section 2)
- Motor failure data (Section 2)
- Discussions with motor program owners
- Aging effects on motors
- Review of EPRI reports providing motor maintenance guidance
- Minimum recommendations to maintain an acceptable level of reliability and provide guidance on refurbishment and spare motors (Section 3)
- The need for motor refurbishment (Sections 3.6 and 3.7)
- Proven motor monitoring based on motor description (Section 4.1)
- Recommended hardware enhancements (Appendix A)

Therefore, as a minimum, the maintenance and monitoring activities recommended in Section 3 should ***always*** be part of a motor maintenance program along with the recommendations for motor refurbishments and availability of spare motors. Keep in mind that the recommended maintenance activities are the ***minimum*** to maintain motor reliability. Additional testing and inspections (online and offline) added to the minimum maintenance activities may be required on critical motors that are known to degrade at an accelerated rate or have known degraded conditions based on equipment history of individual plants.

Preventing in-service failures of motors that can cause plant deratings or shutdowns has a significant cost savings. Therefore, any changes to a motor maintenance program should take into consideration the amount of cost savings from not performing maintenance task, the risk of increased in-service failure potential, and the cost of an in-service failure (i.e., catastrophic failure, loss generation). PMBD [23] is a tool that can be used to assess changes in risk when certain PM tasks are adjusted or not performed. Appendix B has some examples of the changes in risk and/ or reliability using the recommendations in this report coupled with periodicities from other EPRI reports (i.e., [1], [2], [23]). Typically, loss revenue from unit deratings and plant shut downs far out way the cost savings from reducing necessary maintenance to maintain an acceptable level of equipment reliability.

This report endeavored to provide recommendations that would allow plants to reduce their level of effort without unreasonably impacting electric motor reliability.

6
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A
HARDWARE ENHANCEMENTS

Hardware enhancements are sometimes easier to install than continuous monitoring technology because hardware enhancements typically require less engineering resources or design changes.

Some examples of hardware enhancements that the nuclear industry has successfully installed at the time this report was written are listed below:

- **Bearing Hardware Enhancements**
  - Pressure cutoff grease fill fittings



Figure A-1
Pressure Cutoff Grease Fill Fitting

  - Grease relief drain plugs



Figure A-2
Grease Relief Drain Plug

  - Automatic grease and/or oil lubrication devices (adds grease – maintains proper oil level to compensate for leaks)

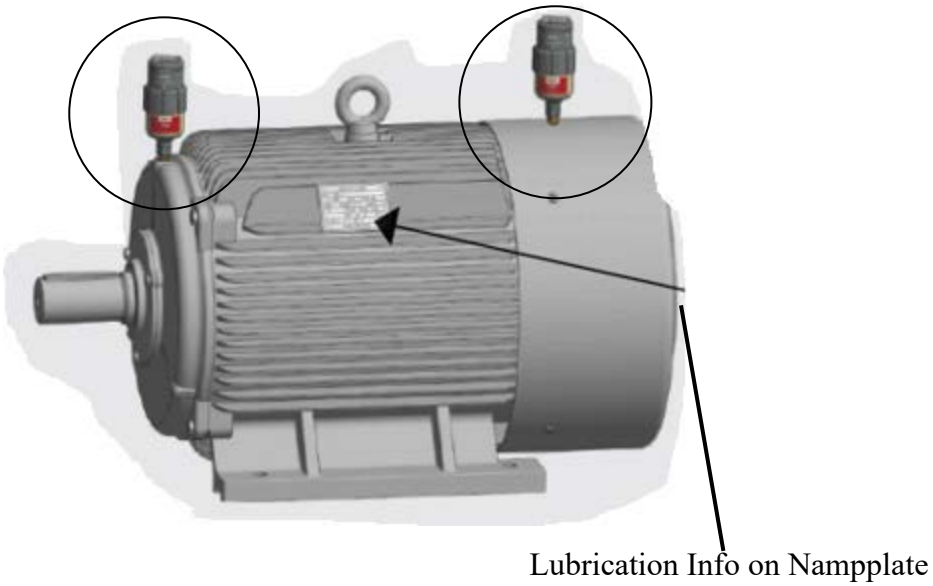


Figure A-3
Automatic Grease Device

– Bearing housing stick-on temperature indicators

- **Motor Lead/Cable Connection Enhancements**
  – Removable motor lead lug/cable lug connection insulators

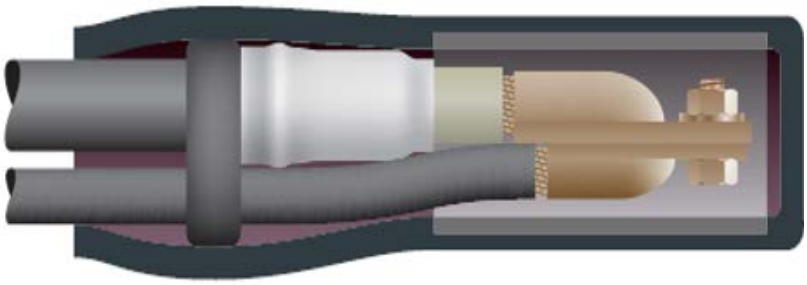


Figure A-4
Example of One Type of 8kV Removable Motor Lead/Cable Connection Insulator

– Flared motor lead lugs to minimize cutting the motor lead strands during crimping



Figure A-5
Example of a Flared Barrel Motor Lead Lug

- **Motor Performance**
  - Start counter/Run Timer – (i.e., plan time-based maintenance – bearing change-out). Some are held in place by a magnetic base.



Figure A-6
Example of a Motor Start Counter and Motor Run Timer

All of the hardware enhancements listed above provide alternate ways of obtaining information or performing maintenance on electric motors. The objectives to installing hardware enhancements are to:

- maintain or improve on motor reliability (i.e., pressure cutoff and relief grease fittings)
- have minimal installation cost (i.e., flared lugs, removal motor lead/cable insulators, start counters and run time monitors, bearing housing temperature indicators)
- and reduce the cost of performing preventive maintenance (i.e., regreasing, bearing temperature monitoring).

The examples listed above are not all inclusive as motor monitoring and maintenance technologies are changing which will provide more available hardware enhancements in the future.

B
VULNERABILTY ANALYSIS USING PMBD

Recommendations provided in this report were developed from surveys from nuclear power plants with electric motor maintenance programs, industry data, and attendees at Large Electric Motor User Group (LEMUG) meetings.

To ensure results of this report are independent and objective, vulnerability analysis was done using the EPRI Preventive Maintenance Basis Database (PMBD). This analysis was done to ensure that the recommendations in this report did not unreasonably increase the risk and did maintain electric motor reliability.

Several screen shots are included in this appendix which represents the change in electric motor failure rate and reliability against an established baseline. There were six vulnerabilities run and the values used to compare against baseline are listed as program 1 in each analysis. There are several things that should be noted when performing these comparisons. First, the recommendations in this report do not address periodicities. The attempt was made to stick with periodicities that were already established by other EPRI reports. Secondly, the recommendations are not laid out exactly as the PMBD; therefore, there had to be some adjustments when there were not one-to-one comparisons for tasks. The baseline program does not provide an option for continuous monitoring recommendations. For example, there are no direct bearing and/or winding temperature monitoring tasks but there is thermography listed. For the comparisons used in this appendix, the custom program (i.e., program 1) uses 1S to substitute for continuous monitoring.

It should be noted that most electric motors in nuclear power plants are in mild environments; thus, the mild environment template was used in some of the comparisons. The vulnerability comparisons were done only using the Task Interval Comparison and varying the classification for each electric motor type (i.e., critical, noncritical).

The results of the vulnerability analysis are displayed in several screenshots.

EPRI ELECTRIC POWER RESEARCH INSTITUTE — Maintenance Analysis Report Generator (MARGe)

Vulnerability Summary: Task Interval Comparison

Component Template: Low Voltage - <600V

Revision Number: 0

Vulnerability Name: Vul Comp Low Voltage Mild Critical

Calculation Inputs

Category: CHM

Stressors: N/A

Task Name	EPRI Baseline	Program 1
Acoustic Monitoring	3 M	NR
Bridge Test Over 20HP	3 Y	2 Y
Motor Performance Testing	3 Y	2 Y
Oil Analysis And Lubrication	1 Y	2 Y
Operator Rounds	1 S	1 S
Refurbishment	AR	AR
System Engineer Walkdown	3 M	3 M
Thermography	6 M	AR
Vibration Monitoring	3 M	3 M

Calculation Results

Failure Rate Compared to Baseline: 1.04

Reliability Benefit Compared to Baseline: 1.00

Figure B-1
PMBD Vulnerability Comparison for Low Voltage Critical Motors

EPRI ELECTRIC POWER RESEARCH INSTITUTE — Maintenance Analysis Report Generator (MARGe)

Vulnerability Summary: Task Interval Comparison

Component Template: Low Voltage - <600V

Revision Number: 0

Vulnerability Name: Vul Comp NHS

Calculation Inputs

Category: NHS

Stressors: Temperature, Vibration

Task Name	EPRI Baseline	Program 1
Acoustic Monitoring	AR	NR
Bridge Test Over 20HP	NR	5 Y
Motor Performance Testing	NR	NR
Oil Analysis And Lubrication	NR	2 Y
Operator Rounds	1 S	1 S
Refurbishment	AR	NR
System Engineer Walkdown	3 M	3 M
Thermography	1 Y	AR
Vibration Monitoring	1 Y	AR

Calculation Results

Failure Rate Compared to Baseline: 0.96

Reliability Benefit Compared to Baseline: 1.01

Figure B-2
PMBD Vulnerability Comparison for Low Voltage Noncritical Motors

EPRI ELECTRIC POWER RESEARCH INSTITUTE — Maintenance Analysis Report Generator (MARGe)

Vulnerability Summary: Task Interval Comparison

Component Template: Medium Voltage <15Kv - Horizontal - Filters - Sleeve Bearing - Oil Lubed

Revision Number: 1

Vulnerability Name: Vul Comp Med Voltage Hor Sleeve Bearing

Calculation Inputs

Category: CHS

Stressors: Contamination, Fluid, Moisture, Temperature, Vibration

Task Name	EPRI Baseline	Program 1
Air Filter Replacement	1 M	AR
Calibration	2 Y	AR
Electrical Tests - Off-line	2 Y	2 Y
Electrical Tests - On-line	3 Y	AR
Mechanical Tests - Off-line	2 Y	AR
Mechanical Tests - On-line	1 Y	1 S
Oil Analysis	6 M	3 M
Oil Lubrication	AR	AR
Operator Rounds	1 S	1 S
Partial Refurbishment	AR	AR
Refurbishment	10 Y	20 Y
System Engineer Walkdown	3 M	3 M
Thermography	6 M	1 S
Vibration Monitoring	3 M	1 S

Calculation Results

Failure Rate Compared to Baseline: 1.46

Reliability Benefit Compared to Baseline: 0.95

Figure B-3
PMBD Vulnerability Comparison for Medium Voltage Horizontal Critical Motors

EPRI ELECTRIC POWER RESEARCH INSTITUTE — Maintenance Analysis Report Generator (MARGe)

Vulnerability Summary: Task Interval Comparison

Component Template: Medium Voltage <15Kv - Horizontal - Filters - Sleeve Bearing - Oil Lubed

Revision Number: 1

Vulnerability Name: Vul Comp NHM Med Vol Hor Noncritical

Calculation Inputs

Category: NHM

Stressors: N/A

Task Name	EPRI Baseline	Program 1
Air Filter Replacement	2 M	AR
Calibration	4 Y	AR
Electrical Tests - Off-line	2 Y	2 Y
Electrical Tests - On-line	3 Y	3 Y
Mechanical Tests - Off-line	2 Y	2 Y
Mechanical Tests - On-line	1 Y	1 Y
Oil Analysis	1 Y	1 Y
Oil Lubrication	AR	AR
Operator Rounds	1 D	1 D
Partial Refurbishment	AR	AR
Refurbishment	10 Y	20 Y
System Engineer Walkdown	3 M	3 M
Thermography	6 M	AR
Vibration Monitoring	6 M	6 M

Calculation Results

Failure Rate Compared to Baseline: 1.11

Reliability Benefit Compared to Baseline: 0.99

Figure B-4
PMBD Vulnerability Comparison for Medium Voltage Horizontal Noncritical Motors

EPRI ELECTRIC POWER RESEARCH INSTITUTE — Maintenance Analysis Report Generator (MARGe)

Vulnerability Summary: Task Interval Comparison

Component Template: Medium Voltage <15Kv - Vertical - Solid Shaft - Tilt Pad - Sleeve Guide - Oil Lubed

Revision Number: 1

Vulnerability Name: Vul Comp CHM Med Voltage TSP Critical

Calculation Inputs

Category: CHM

Stressors: N/A

Task Name	EPRI Baseline	Program 1
Air Filter Replacement	2 M	AR
Calibration	2 Y	AR
Electrical Tests - Off-line	2 Y	2 Y
Electrical Tests - On-line	3 Y	3 Y
Grease Lubrication	AR	NR
Mechanical Tests - Off-line	2 Y	2 Y
Mechanical Tests - On-line	1 Y	1 S
Oil Analysis	6 M	3 M
Oil Lubrication	AR	AR
Operator Rounds	1 S	1 S
Partial Refurbishment	AR	AR
Refurbishment	10 Y	20 Y
System Engineer Walkdown	3 M	3 M
Thermography	6 M	AR
Vibration Monitoring	3 M	1 S

Calculation Results

Failure Rate Compared to Baseline: 1.11

Reliability Benefit Compared to Baseline: 0.99

Figure B-5
PMBD Vulnerability Comparison for Medium Voltage Vertical Critical Motors

EPRI ELECTRIC POWER RESEARCH INSTITUTE — Maintenance Analysis Report Generator (MARGe)

Vulnerability Summary: Task Interval Comparison

Component Template: Medium Voltage <15Kv - Vertical - Solid Shaft - Tilt Pad - Sleeve Guide - Oil Lubed

Revision Number: 1

Vulnerability Name: Vul Comp NHM Med Vol TSP Noncritical

Calculation Inputs

Category: NHM

Stressors: N/A

Task Name	EPRI Baseline	Program 1
Air Filter Replacement	2 M	AR
Calibration	4 Y	AR
Electrical Tests - Off-line	2 Y	2 Y
Electrical Tests - On-line	3 Y	3 Y
Grease Lubrication	AR	NR
Mechanical Tests - Off-line	2 Y	2 Y
Mechanical Tests - On-line	1 Y	1 Y
Oil Analysis	1 Y	1 Y
Oil Lubrication	AR	AR
Operator Rounds	1 D	1 D
Partial Refurbishment	AR	AR
Refurbishment	10 Y	20 Y
System Engineer Walkdown	3 M	3 M
Thermography	6 M	AR
Vibration Monitoring	6 M	6 M

Calculation Results

Failure Rate Compared to Baseline: 1.10

Reliability Benefit Compared to Baseline: 0.99

Figure B-6
PMBD Vulnerability Comparison for Medium Voltage Vertical Noncritical Motors

The results of the vulnerability analysis illustrate the changes in risk and/or reliability when adjusting maintenance tasks.



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