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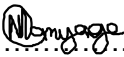
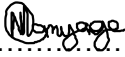
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1. INTRODUCTION

This Work Instruction (WI) provides the Eskom requirements for the refurbishment of medium voltage electric motors in the Generation business.

2. SUPPORTING CLAUSES

2.1 SCOPE

This WI covers the minimum requirements for the stripping and assessment, redesign of weak components, general updating of design in accordance with modern design practice, rewinding, repair, impregnation, inspection, testing and certification of repaired medium voltage motors from 3.3kV up to 15kV voltage ratings.

2.1.1 Purpose

This WI provides Eskom requirements for the refurbishment of medium voltage electric motors for power stations, and acts as a WI to engineers, station personnel and repairers when involved in the process of refurbishing medium voltage electric motors.

2.1.2 Applicability

The requirements of this WI are applicable to all Generation business that utilise medium voltage electric motors in their plants.

2.1.3 Exclusions

While this WI contains quality control and assurance requirements, it does not cover all material and workmanship issues that shall be addressed by the Repairer through a duly certified ISO 9001 Quality Management System.

This WI is applicable primarily to medium voltage induction motors and does not fully cater for the requirements of synchronous motors and other special designs such as Boiler Circulating Pumps and Nuclear environment machines.

2.2 NORMATIVE/INFORMATIVE REFERENCES

The following standards contain provisions that, through reference in the text, constitute requirements of this WI. All standards are subject to revision and parties involved in refurbishment processes based on this WI are encouraged to apply the most recent revisions of the standards listed below. Only the Eskom standards listed on this document may be obtained from Eskom as part of the contract documents. Parties using this document shall apply the most recent editions of the documents listed in the following paragraphs.

2.2.1 Normative

- | | | |
|-----|-------------------|---|
| [1] | ISO 9001, | <i>Quality Management Systems.</i> |
| [2] | BS EN 50209, | <i>Test of insulation of bars and coils of high-voltage machines.</i> |
| [3] | IEEE Std 522 | <i>IEEE Guide for Testing Turn Insulation of Form-Wound Stator Coils for Alternating-Current Electric Machines.</i> |
| [4] | SANS IEC 60034-1, | <i>Rotating electrical machines – Part 1: Rating and performance.</i> |

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- [5] SANS IEC 60034-2-1, *Rotating electrical machines – Part 2-1: Standard Methods for determining losses and efficiency from tests (excluding machines for traction vehicles)*
- [6] SANS IEC 60034-2-2, *Rotating electrical machines – Part 2-2: Specific methods for determining separate losses of large machines from tests - Supplement to IEC 60034-2-1.*
- [7] SANS IEC 60034-2-3, *Rotating electrical machines – Part 2-3: Specific test methods for determining losses and efficiency of converter-fed AC motors.*
- [8] SANS IEC 60034-5, *Rotating electrical machines – Part 5: Classification of degrees of protection provided by the integral design of rotating electrical machines (IP code) – Classification.*
- [9] SANS IEC 60034-6, *Rotating electrical machines – Part 6: Methods of cooling (IC Code)*
- [10] SANS IEC 60034-7, *Rotating electrical machines – Part 7: Classification of types of construction, mounting arrangements and terminal box position (IM code)*
- [11] SANS IEC 60034-8, *Rotating electrical machines – Part 8: Terminal markings and direction of rotation.*
- [12] SANS IEC 60034-9, *Rotating electrical machines – Part 9: Noise limits.*
- [13] SANS IEC 60034-11, *Rotating electrical machines – Part 11: Built-in thermal protection. Chapter 1: Rules for protection of rotating electrical machines*
- [14] SANS IEC 60034-12, *Rotating electrical machines – Part 12: Starting performance of single-speed three-phase cage induction motors.*
- [15] SANS IEC 60034-14, *Rotating electrical machines – Part 14: Mechanical vibration of certain machines with shaft heights 56 mm and higher – Measurement, evaluation and limits of the vibration.*
- [16] SANS IEC 60034-15, *Rotating electrical machines – Part 15: Impulse voltage withstand levels of rotating a.c. machines with form-wound stator coils.*
- [17] SANS IEC 60034-16-1, *Rotating electrical machines – Part 16: Excitation systems for synchronous machines: Chapter 1: Definitions*
- [18] SANS IEC 60034-16-2, *Rotating electrical machines – Part 16: Excitation systems for synchronous machines: Chapter 2: Models for power system studies.*
- [19] SANS IEC 60034-16-3, *Rotating electrical machines – Part 16: Excitation systems for synchronous machines: Section 3: Dynamic performance.*
- [20] SANS IEC 60034-18-1, *Rotating electrical machines – Part 18: Functional evaluation of insulation systems – Section 1: General guidelines.*
- [21] SANS IEC 60034-18-21, *Rotating electrical machines – Part 18: Functional evaluation of insulation systems – Section 21: Test procedures for wire-wound windings – Thermal evaluation and classification.*
- [22] SANS IEC 60034-18-22, *Rotating electrical machines – Part 18: Functional evaluation of insulation systems – Section 22: Test procedures for wire-wound windings – Classification of changes and insulation component substitutions.*
- [23] SANS IEC 60034-18-31, *Rotating electrical machines – Part 18: Functional evaluation of insulation systems – Section 31: Test procedures for form-wound windings – Thermal evaluation and classification of insulation systems used in machines up to and including 50 MVA and 15 kV.*

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- [24] SANS IEC 60034-18-32, *Rotating electrical machines – Part 18: Functional evaluation of insulation systems – Section 32: Test procedures for form-wound windings – Electrical evaluation of insulation systems used in machines up to and including 50 MVA and 15 kV.*
- [25] SANS IEC 60034-18-33, *Rotating electrical machines – Part 18: Functional evaluation of insulation systems – Section 33: Test procedures for form-wound windings – Multifactor functional evaluation – Endurance under combined thermal and electrical stresses of insulation systems used in machines up to and including 50 MVA and 15 kV.*
- [26] SANS IEC 60034-18-34, *Rotating electrical machines – Part 18-34: Functional evaluation of insulation systems – Functional evaluation of insulation systems – Test procedures for form-wound windings – Evaluation of thermomechanical endurance of insulation systems.*
- [27] SANS IEC 60034-23, *Rotating electrical machines – Part 23: Specification for the refurbishing of rotating electrical machines.*
- [28] SANS IEC 60034-25, *Rotating electrical machines Part 25: Guide for the design and performance of a.c motors specifically designed for converter supply.*
- [29] SANS IEC 60034-26, *Rotating electrical machines Part 26: Effects of unbalanced voltages on the performance of three-phase cage induction motors.*
- [30] SANS IEC 60034-27, *Rotating electrical machines Part 27: Off-line partial discharge measurements on the stator winding insulation of rotating electrical machines.*
- [31] SANS IEC 60034-29, *Rotating electrical machines Part 29: Equivalent loading and superposition techniques - Indirect testing to determine temperature rise.*
- [32] SANS IEC 60034-30, *Rotating electrical machines Part 30: Efficiency classes of single- speed, three-phase, cage-induction motors (IE-code).*
- [33] SANS IEC 60050 (411), *International Electrotechnical Vocabulary (IEV) – Chapter 411: Rotating machines*
- [34] SANS IEC 60072-1, *Dimensions and output ratings for rotating electrical machines – Part 1: Frame numbers 56 to 400 and flange numbers 55 to 1 080.*
- [35] SANS IEC 60072-2, *Dimensions and output ratings for rotating electrical machines – Part 2: Frame numbers 355 to 1 000 and flange numbers 1 180 to 2 360.*
- [36] SANS 600317:16 *Specification for particular types of winding wires*
- [37] SANS IEC 60851, *Winding wires - Test methods Part 1-6*
- [38] SANS IEC 60085, *Thermal evaluation and classification of electrical insulation.*
- [39] SANS IEC 60270, *Partial discharge measurements.*
- [40] Eskom [240-50237155](#), *New MV Induction Motor Procurement Standard*
- [41] Eskom [240-54783039](#), *New MV Induction Motor Technical Schedule AB Template.*
- [42] Eskom 240-87739380, *Motor Repair and Refurbishment Assessment Form.*
- [43] Eskom [240-56361435](#), *Transport of Power Station Electric Motors standard.*
- [44] Eskom [240-56360387](#), *Storage of Power Station Electric Motors standard.*
- [45] Eskom 559-142380811, *MV Motor Repair- Refurbishment Technical Schedule A&B.*
- [46] Eskom 559-69067162, *Eskom Power Station Motor Breakdown Form.*
- [47] Eskom 240-106628253, *Eskom Welding Standard.*

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2.2.2 Informative

[48] EPRI 1011892 Guideline for the Specification of Replacement and Spare AC Squirrel-Cage Induction Motors having Voltage Ratings of 2,300 V to 13,200 V; EPRI. Palo, Alto, CA.

[49] 112, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators.

2.3 DEFINITIONS

Unless otherwise indicated, the definitions of IEC 60050-411 shall apply, in addition to the following:

- A. **Bearings:** A stationary member or assembly of stationary members in which a shaft is supported and may rotate.
- B. **Critical Motors:** Motors whose failure in service would have an appreciable probability of causing loss of availability of generating plants, or of causing unsafe conditions for personnel or plant.
- C. **DC Step Voltage test:** The test is a controlled over-voltage test where designated voltage increments are applied at designated times and leakage current is recorded. The time increments can be constant or graded.
- D. **Employer:** The Eskom business unit engaging in refurbishing or repairing electrical motors to which this document is applicable
- E. **Overhaul:** Restoration of a motor that is not faulty to fully serviceable condition. A basic refurbishment with limited replacement of components (e.g., bearing replacements).
- F. **Polarization Index (PI):** Variation in the value of insulation resistance with time.
- G. **Refurbishing:** The total process of restoring a machine or component that has become inadequate for continued use with normal maintenance, thereby making it suitable for an extended period of service. This may include re-evaluating the service conditions and use of the motor and possible redesigning of the motor to meet the new requirements. Refurbishment includes overhaul and repair.
- H. **Repair:** Steps required to rework or replace motor components to restore the motor to original design specifications.
- I. **Repairer:** Motor Repair Service Provider
- J. **Rewind:** The process that includes the removal and replacement of the stator or rotor winding system in the motor.
- K. **Rotor End Float:** This applies to horizontal motors with sleeve or tilting pad bearings. It is the total rotor axial movement of an uncoupled motor when the rotor is pushed from one extremity to the other and is limited by the distance between shaft journal shoulders and the width of the bearing.
- L. **Site:** Eskom premises
- M. **Subcontractors:** A service provider hired and working under the main contractor (Repairer). The contract agreement is with the main contractor and not the Employer.
- N. **Task Order:** A formal request for services by the Employer under an existing contract.

2.3.1 Disclosure Classification

Controlled Disclosure: Controlled Disclosure to external parties (either enforced by law, or discretionary).

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2.4 ABBREVIATIONS

Unless otherwise indicated, ISO abbreviations shall apply.

Abbreviation	Description
AC	Alternating Current
CACA	Cool Air Cool Air
CACW	Cool Air Cool Water
CPM	Cycles per Minute
DAR	Dielectric Absorption Ratio
DC	Direct Current
DE	Drive End
ELCID	Electromagnetic Core Imperfection Detection
EN	Euronorm or European Standards
ETD	Embedded Temperature Detector
HV	High Voltage
ID	Inside Diameter
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IR	Insulation Resistance
ISO	International Organization for Standardization
ITP	Inspection and Test Plan
MV	Medium Voltage
N/A	Not Applicable
NB	Nota Bene (note well)
NDE	Non-Drive End
NDT	Non-Destructive Testing
NEC	New Engineering Contract
NEMA	National Electrical Manufacturers Association
OEM	Original Equipment Manufacturer
PCM	Process Control Manual
PI	Polarization Index
QA	Quality Assurance
QA&C	Quality Assurance and Control
QC	Quality Control
QCP	Quality Control Plan
RMS	Root Mean Square
RTD	Resistance Temperature Detector
SANS	South African National Standards
SC	Study Committee
SOW	Scope of Work

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Abbreviation	Description
THD	Total Harmonic Distortion
VPI	Vacuum Pressure Impregnation
WI	Work Information

2.5 RELATED/SUPPORTING DOCUMENTS

[50] N/A.

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3. SUPPLIER AND QUALITY CONTROL REQUIREMENTS

3.1 SUPPLIER ELIGIBILITY

- A. Eskom shall ascertain that the Repairer has adequate facility, equipment and skilled personnel to undertake the proposed site scope of work before contract award.
- B. Only a Repairer that owns or leasing a MV motor refurbishment workshop for the duration of the contract are eligible to refurbish MV Motors for Eskom. Subcontracting of a refurbishment workshop is not allowed. Site specific requirement shall be defined in 559-142380611 MV Motor Refurbishment Technical Schedule A&B.
- C. The Repairer shall have skilled personnel in engineering, quality management, fitters, armature winders and vibration specialist, all with appropriate certifications and contracted for the duration of the contract.
- D. Subcontracting of certain works and testing facilities shall be defined in 559-142380611 MV Motor Refurbishment Technical Schedule A&B as other refurbishment works and testing are done by Subcontractors and also depends on site scope of work.
- E. All Subcontractors utilised by the Repairer are to be approved by the Employer prior to the Repairer utilising such Subcontractors.
- F. A **Site visit** shall be conducted during technical evaluation to verify the workshop capability and compliance to the requirements in this document and 559-142380611 MV Motor Refurbishment Technical Schedule A&B.

3.2 QUALITY CONTROL AND ASSURANCE

3.2.1 Quality Control

- A. The Repairer shall hold a valid formal certification confirming full compliance with ISO 9001. Such certification shall be accredited by an independent Quality Management System certification body.
- B. The Repairer shall provide and maintain an Eskom-approved quality control and inspection program. This program shall include, but not limited to, the requirements for a Quality Control Plan (QCP) that covers all component inspections, tests, manufacturing procedures, and hold points for the motor contract. An addendum to the QCP shall be the Inspection and Test Plan (ITP), which only shows items/tasks that require input by the Employer, e.g. acceptance, approval, inspection, witnessing, and hold point.
- C. Refurbishment of the MV motors shall not start until the Repairer receives the Employer's approval of the QCP and ITPs.
- D. The Repairer's ITP shall only include items as per the scope of work agreed with the Employer and will be required before each Task Order is executed.
- E. All materials and parts that are necessary for the motor refurbishment shall be new and provided with relevant information and certifications.
- F. Unless otherwise specified or approved by Eskom, all materials, parts and processes shall comply with the most recent Eskom, SANS and/or IEC standards and certification applicable. Should conflict occur between the standards, the former shall apply, in sequence.

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- G. Components that are tested and functional shall be re-used unless the agreed SOW or the Employer requires replacement with new.
- H. All components that are faulty should be recorded and put aside for inspection by the Employer. The Employer shall indicate the disposal of the faulty components.
- I. During motor refurbishment and assembly, component protection and clean conditions shall be practiced ensuring no materials are damaged and foreign materials that would affect motor performance are not left inside the motor.
- J. Welding shall be undertaken by qualified welders and, where necessary, stress relieving shall be applied prior to machining. Welding shall follow the Eskom welding standard in 2.2.1. No welding, burning in, filling, plugging up or metal deposition to correct defects in any component will be permitted unless agreed to by Eskom in writing, following an inspection of the defect by Eskom or its authorized representative.

3.2.2 Inspections

- A. At any phase of the Works, the Employer or its authorized representative reserves the right to inspect motors and all their components at the Repairer's workshop. By entering into a contract with the Employer, the Repairer therefore, consents the Employer or its authorized representative to an unlimited access to the Repairer's premises/workshop, including Subcontractor's premises at all reasonable times to the extent necessary to assess compliance with the provisions of this and such other documents as may apply to the refurbishment of MV motors. Such inspections shall not relieve the Repairer of its obligations or responsibilities under the contract.
- B. If new and/or replacement parts are procured, the Employer has the right to inspect these parts. Technical documentation shall be made available to the Employer for inspection. The documentation shall include but is not limited to the following, where applicable:
 - B.1. New stator core steel test and dimensional data,
 - B.2. Technical sheets of original and replacement stator coils, testing, and insulation system,
 - B.3. Manufacturer's technical data for new stator lead cables,
 - B.4. Details of original and replacement rotor bars and end rings,
 - B.5. Details of original and replacement rotor shaft and spider arms,
 - B.6. VPI Resin type and maintenance data,
 - B.7. Burn-out and dry-out oven temperature charts,
 - B.8. New bearing inspection and tests data, and
 - B.9. Testing and Inspection reports.
- C. The Repairer is responsible for managing the requirements of the ITP. The Repairer shall notify the Employer of its intention to conduct inspections and tests listed in the ITP, giving no less than 2 working days' notice for the Employer's representative to witness the ITP task. The Employer reserves the following rights on the ITP tasks:
 - C.1. Request, which shall not be unduly rejected, performing of the test as per the Employer's valid test procedure and/or to the Employer's reasonable satisfaction.

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- C.2. Conduct tests/inspections not contained in the agreed ITP between the Employer and Repairer. The costs for such additional test/inspection measurements shall either be for the Employer's account, if the motor refurbishment and/or performance has not deviated from any contract requirement or the Repairer's account if the motor refurbishment and/or performance has deviated from any contract requirement.
- C.3. To instruct the Repairer to repeat any task conducted without notifying the Employer, at the Repairer's cost.
- C.4. To return to the Repairer's workshop and at the Repairer' cost, motors despatched to an Eskom site without the required inspection/s and approvals.
- D. Deviation reports shall be provided to the Employer for evaluation and acceptance, which shall not be unduly declined. The Employer's acceptance of a manufacturing deviation does not, in any way, relieve the Repairer of its obligation or responsibilities for negative consequence/s of the deviation. Failure to provide full deviation reports may, at the Employer's discretion; result in the Employer rejecting the refurbished or repaired motors.

4. REFURBISHMENT PROCESS REQUIREMENTS

- A. A motor due for refurbishment will either be deemed to have failed or it shall be scheduled for overhaul by the Employer.
- B. There are two phases in the refurbishment process of an MV electric motor:
 - B.1. There is **Phase I**, which is commonly referred to as "*collect, strip, and assess*" phase.
 - B.2. Detailed assessment of the motor is done in order to determine the SOW.
 - B.3. Once the SOW is concluded, the process enters **Phase II**, in which the motor is repaired or refurbished and delivered back to site as per the final scope of work determined in **Phase I**.
- C. This WI is structured to describe, in sequence, the processes to be undertaken within the two phases. A flowchart illustrating the process of the two phases is described in APPENDIX A.

4.1 PHASE I REQUIREMENTS

4.1.1 Motor failures and planned refurbishments

- A. Once a motor has failed during service or once a motor, which is in a serviceable condition, has been planned for refurbishment, the following activities shall be conducted in sequence:

4.1.1.1 Breakdown Report

- A. A motor assessment shall be conducted by the Employer while the motor is in-situ before its removal from the installation base.
- B. The assessment includes visual inspection of the motor and its surroundings, interfaces (e.g. bearings, heat exchanger, etc.) and electrical testing (e.g. IR, winding resistance, etc.) were applicable. All abnormalities must be recorded and photographs taken.
- C. A Motor Breakdown Form 559-69067162 shall be completed by the Employer to capture the findings for use during root causes analysis, repair and to be shared with the Repairer.

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4.1.1.2 Assessment SOW

- A. The Employer shall provide an Assessment SOW for site dismantling, collection, and assessment of the motor by the Repairer based on the investigations included in the Motor Breakdown Form.
- B. Where the refurbishment contract exists, the general scope of work or tasks may already exist and just need confirmation of the applicable tasks required for assessment.
- C. The Employer shall give authorisation to start with the refurbishment work for each motor.

4.1.2 Motor Site Collection and Delivery

- A. Transport of motors shall be in accordance with document 240-56361435 Transport of Power Station Electric Motors Standard.
- B. The transportation of motors which are still in a serviceable condition shall be done by the Repairer who shall take the necessary care to prevent damage during transportation.
- C. The following requirements shall be observed:
 - C.1. The motor collection point and lifting requirements shall be managed by the Employer.
 - C.2. Only authorised Employer personnel shall load the motor to the Repairer's transport.
 - C.3. The Employer shall supply tools and resources necessary to clamp the motor shaft before transport leaves the collection point.
 - C.4. The Employer is responsible to inform the Repairer of specific Business Unit requirements such as security requirements and collection times.
 - C.5. The Repairer shall provide the appropriate vehicle(s) and other tools to hold down and also cover the motor(s).

4.1.3 Motor Assessment Process - "Strip and Assess"

- A. The Repairer shall implement the contracted strip and assess SOW, without deviation, as specified in the following sub-sections and record results in 240-87739380 Motor Repair and Refurbishment Assessment Form.

4.1.3.1 Incoming Inspections before Dismantling

- A. The Repairer shall, on receipt of the motor, perform the initial inspection and tests listed below and in the Assessment Form and SOW before dismantling. The tests are to determine the probable cause of the failure if any, record the findings, and to determine additional work which may be required.
- B. The following is required:
 - B.1. A visual inspection to assess the general condition of the motor frame for cracks, broken welds and missing parts.
 - B.2. Photographs are to be taken to document the motor construction including accessories.
 - B.3. Record any missing components or parts of the motor and report to the Employer.
 - B.4. Perform the incoming routine tests including:
 - IR and PI tests per phase as per Sub-section 4.4.2.2.1,

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- Phase resistance test per phase as per Sub-section 4.4.2.2.2,
 - Bearing insulation measurement as per Sub-section 4.4.2.4.2,
 - RTDs (PT100) resistance test, Thermocouple functionality test, Space heater insulation and resistance test as per Sub-section 4.4.2.4.1.
- B.5. Failed components shall be identified during the incoming inspection. the Repairer shall attempt to verify the cause and reflect the findings in the Motor Failure report.
- B.6. Bearings and shafts shall be checked for any obvious problems by manual rotation of the rotor, if possible.
- The Repairer shall ensure that the bearings are adequately lubricated before performing the manual rotation check.
 - If the motor is fitted with sleeve bearings, the manual rotation test may be omitted, but the bearings and journals shall be opened and checked.
- B.7. For the motor in a working condition and where a no-load test is required before overhaul, the following test will be done as per as per Sub-section 4.4.5.3.:
- Test run for vibration measurements, especially for motor under warranty claim.
 - Bearing temperature rise test.
 - No load current measurements and phase balance test.
 - Shaft voltage measurements as per Sub-section 4.4.2.4.2
 - Noise measurements or sound level checks.

4.1.3.2 Motor Dismantling

- A. After completing the incoming inspection, the motor shall be dismantled to conduct the pre-cleaning assessment.
- B. A motor shall be dismantled as follows:
- B.1. A motor that involves either warranty or insurance claims shall not be disassembled without the Employer giving a written permission for the Repairer to commence with the disassembling. Arrangements shall be made for interested and affected parties to witness the dismantling. The Employer Assessment SOW shall have a HOLD-POINT for such a requirement. The Repairer is required to take pictures and records throughout the disassembly.
 - B.2. All motor components shall be marked with either the motor manufacturer's serial number or Repairer's job number during disassembly. Any new stamp identifications added shall be applied to low stress areas with low stress punches. Bolts and small parts from the motor shall be stored in dedicated containers marked with a Repairer's job number.
 - B.3. End brackets and frames shall be clearly match-marked.
 - B.4. All components are to be properly stored and the storage conditions should not adversely affect the components.
 - B.5. Old nameplates or stamp identifications from previous refurbishments on the motor are NOT to be removed.

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B.6. Rotor removal shall utilise one or two cranes to move the shaft, with a close-fitting pipe installed over one end of the shaft to act as a shaft extension. Attention shall be paid to the following quality control requirements during this process:

- The location, make, type, size, clearances and orientation of bearings,
- Care shall be taken that the slings do not damage either the bearing surfaces or the rotor.
- Under no circumstances shall the stator windings be touched by any of the parts being moved.

B.7. Additional information gathered during disassembly inspections shall be used to support the cause of failure analysis. Failure causes shall be discussed with the Employer before repair work proceeds.

4.1.3.3 Pre-cleaning Assessment

- A. Prior to the motor being cleaned, all components shall be inspected and tested. Due to motor contamination however, some components may require cleaning for a complete inspection and testing.
- B. The Repairer shall notify the Employer of any anomalies identified and shall document findings with photographs.

4.1.3.3.1 Stator Assessment

- A. The assessment of the stator shall include the following minimum requirements:
- A.1. The motor lead insulation shall be inspected for cracks, frays, signs of brittleness, and swelling from oil contamination and other contaminants.
 - A.2. Motor lead lugs shall be inspected for signs of overheating. A pull check for loose crimp connections shall be performed.
 - A.3. Inspect the stator insulation for signs of partial discharge (white powder-like deposits around line-to-line coil insulation), cracking at blocking and bracing, dryness, brittleness or puffiness.
 - A.4. End-winding support and bracing shall be inspected for looseness, missing and/or broken parts and evidence of abrasion powder.
 - A.5. Stator slot wedges shall be inspected for looseness, missing and/or broken parts.
 - A.6. Inspect the stator core laminations for looseness, rubs, localized overheating and vent duct blockages.
 - A.7. Core clamping fingers and duct spacers shall be checked for looseness and missing parts.
 - A.8. Evidence of oil, water, rust or dust contamination.
 - A.9. Perform **inter-turn insulation test** as per Subsection 4.4.2.2.6 Impulse testing.
 - A.10. Perform a **rated core flux test** as per Sub-section 4.4.2.3 Core flux Test.
 - A.11. If the stator core has insulated through-bolts, the insulating washers at the ends shall be checked for cracks. The insulation resistance between the bolts and core should be measured and recorded.
 - A.12. Perform a visual inspection of the stator winding RTD's or thermocouples if fitted.

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- A.13. Air baffles and mounting hardware shall be inspected for defects and missing parts.
- B. If the motor has been subject to an insulation failure, the following stator assessment requirements are additional to the above inspection points, and shall be met before the winding is cleaned:
- B.1. The Employer is to be notified of the date, time and place to assess the insulation failure.
 - B.2. The Repairer shall produce a diagram of the original stator winding showing coil groupings, parallel/phase and phase connections prior to the removal of the winding from the stator. This diagram shall include the locations of all winding RTD's, or thermocouples. The location of the phase groups shall be referenced to a fixed point on the stator core. Winding and temperature detector terminal identifications shall be recorded on this diagram.
 - B.3. The failed coil/s or leads shall be identified and isolated from the other winding coils. The point of flashover shall also be clearly identified. The identification shall be in the form of a winding drawing showing the location, both physically and electrically, in the winding circuit.
 - B.4. For insulation failure (e.g. leads or connection rings) that is reparable, the other coils shall have the insulation system tested using AC electrical test methods, which shall include the IR tests, Surge tests and AC Hi-pot tests at 1.5 times the rated voltage.
 - B.5. For reparable coils, the damaged coil/s shall be carefully removed to avoid damage to adjacent healthy winding and insulation.
 - B.6. The Employer reserves the right to request the Repairer's permission to remove the failed coil/s, and any other coil that the Employer may deem necessary for failure analysis, from the Repairer's workshop. The Repairer shall not deny the Employer's request for coil/s, or part thereof, to be removed from the Repairer's Workshop.
 - B.7. Oven burn-out of the winding before the 'cold' removal/stripping, of the failed coil/s, is not allowed.
 - B.8. Dissection of the failed stator coil is essential. Dissection of adjacent coils which have not failed but not repairable is also essential, although sometimes the area immediate to the failure has been completely burned away by the fault. The Employer shall conduct the analysis, with the assistance of the Repairer's suitably qualified personnel, if so requested.
 - B.9. The coil dimensions, coil pitch, space between endwinding coils, endwinding supports, insulation type, stress grading, airgap and type of wedges shall be recorded and photos taken before coil removal.
 - B.10. The size and number of stator slots, turns per coil, strand number and dimensions shall be recorded after coil removal

4.1.3.3.2 Rotor, Shaft and Fan Assessment

The assessment shall include the following checks:

- A. The rotor shall be removed without damaging the wedges, core and windings.
- B. The rotor core shall be inspected for looseness, loose, cracked, or missing clamping fingers and vent duct spacers, rubs, localized heating and blocked vent ducts. If overheating is found, inspection for signs of cracked rotor laminations or core migration is required. If defects are found, the Employer

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shall be contacted prior to any cleaning in order for an own inspection and discussion of repair strategy to take place.

- C. Perform an **ELCID test** on rotor core to quantify the defects noticed as per subsection 4.4.2.4.3.
- D. Inspect, with magnification, the rotor bars and end rings for cracks, looseness, signs of localized heating and cage migration. If cracks are suspected, a dye penetrant and ultraviolet light method test is to be performed.
- E. Perform **Rotor bar tests** as described in subsection 4.4.2.4.3 to check for breaks in the rotor cage bars.
- F. Measure and record the number and size of rotor slots, rotor bars and endrings including photos.
- G. The motor fans shall be visually inspected for cracked or loose blades, and on welds and hubs using the dye penetrant and ultraviolet light method. Looseness between the fan and its hub shall be checked.
- H. Perform **NDT tests** on whole Rotor shaft and fans. Visually inspect the rotor shaft, journals and spider for cracks using the dye penetrant and ultraviolet light methods.
- I. Check the straightness of shaft extensions, bearing journals, and rotor body by conducting total run-out measurements as contained in the mechanical checks section. Measure and record the shaft extension run out of the motor shaft.

4.1.3.3.3 Bearing Assessment

The assessment of bearing assemblies shall include the following:

- A. Inspection and measurement of sleeve bearing journal housings and rolling-element bearing housings for correct fits to their respective bearings, in accordance with design values from either the motor OEM drawings or the bearing manufacturer's catalogue. From these measurements comparison is required for the bearing housing fit to the design values.
 - A.1. Recording bearing fit dimensions.
 - A.2. Performing a visual check of the bearing housing bore for evidence of fretting that may indicate a loose fit between the bearing and its housing.
- B. Check bearing white metal surfaces for evidence of wipes and wear. Measurement of the sleeve bearing bores is required at three locations and records of measurements to be in an Assessment Form. If the white metal wear pattern indicates misalignment or other problems, the details of this shall be recorded.
- C. Determine the bore roundness of sleeve bearings as per subsection 4.4.4.1 Mechanical checks during assembly.
- D. Inspect oil rings and oil seals for signs of excessive wear and any other defects.
- E. Check oil rings for roundness, roughness of edges, and, if applicable, tightness of split oil-ring screws. Roundness shall be within 0.127mm. Check the oil-ring viewing port glass in the bearing housing for transparency.
- F. The nominal seal-to-shaft clearances are to be documented by measuring the seal bores and using measured shaft diameters.

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- G. Check for evidence of rubs and leaks on the water coolant spiral of motors with water cooled oil reservoir bearings. Coolers shall be inspected for evidence of erosion and corrosion and shall be pressure tested. The pressure test shall be conducted for 30-minutes as follows:
 - G.1. Either a water pressure test at 125% of the cooler water supply system pressure, or the cooler manufacturer's test pressure. Under no circumstances should the cooler manufacturer's test pressure be exceeded.
 - G.2. For an air pressure test or other gas such as nitrogen or helium, the cooler shall not be greater than 500 kPa.
- H. Check bearing brackets for cracks or any other defects.
- I. Check the bearing insulation on the outside of the sleeve bearings for damage, wear, and overall dimensions.

4.1.3.3.4 Heat Exchanger Assessment

- A. Heat exchangers fans shall be visually inspected for cracked or loose blades, and on welds and hubs using the dye penetrant and ultraviolet light method. Looseness between the fan and its hub shall be checked.
- B. Air-to-Air (CACA) heat exchangers shall be visually inspected for cracked tubes, loose air deflectors and blockages.
- C. The tube side of the air-to-water heat exchanger shall be hydrostatically tested at 1.3 times the design pressure, for one hour. No leakage is permitted, including at gasketed joints.
- D. The Repairer shall be responsible for obtaining all relevant certificates including those required for pressure parts.
- E. Used gaskets/seals, inserted between the cooler housing and the motor, shall be replaced with similar or better materials to avoid dust and water ingress.
- F. The cooler gaskets/seals shall also be replaced with similar or better materials to avoid water leaks.

4.1.3.3.5 Assessment of Motor Accessories

The motor accessories shall be checked as follows:

- A. Space heaters and the heater wiring shall be functionally and visually checked. If significant corrosion is identified inside the motor, the root cause is to be investigated.
- B. Bearing, winding and air temperature detectors shall be functionally and visually checked.
- C. Surge arrestors shall be functionally and visually checked.
- D. All other accessories shall be functionally checked.

4.1.3.4 Cleaning

- A. Stator and rotor that are found to be clean and uncontaminated shall not be washed, unless agreed with the Employer as part of the scope of work.
- B. The cleaning and drying method should not adversely affect the insulation ageing and integrity.

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- C. If the windings (stator and rotor) are contaminated with any form of dust which has not hardened on the winding components, cleaning shall be by compressed air or blower only. The pressure at which air shall be blown through the windings shall be adequate for dust removal without damaging the insulation exterior.
- D. If the winding/s (stator and rotor) are contaminated with any form of dust and/or oil/grease/water, the windings shall be cleaned as follows:
 - D.1. Stator windings with hardened contaminants and blocked air vents shall be soaked with an appropriate detergent designed for motor cleaning prior to pressure cleaning. Cleaning by means of solvents may only be utilized where it is suitable for the application. Prior to the application of solvents, approval is to be obtained from the Employer.
 - D.2. The motor is to be cleaned by low-pressure steam with a maximum pressure of 206 kPa (30psi).
 - D.3. In the absence of a low-pressure steam, a power washer with a maximum nozzle pressure of 1379 kPa (200psi) shall be used.
 - D.4. During the cleaning process, care is to be taken to ensure that foreign particles are not lodged into the insulation (cracks and crevices) where it can remain trapped.
 - D.5. Where cleaning methods such as dry-ice cleaning is recommended or utilized, a method statement is to be provided to the Employer for review. The method statement is to include preventative measures to mitigate the risk of insulation damage.
 - D.6. Any detergent, or other cleaning agent applied, shall be completely flushed from the stator after cleaning.
- E. Cleaning shall be considered complete when all the air-vents have been unblocked and all contaminants on the component surfaces have been removed. The Repairer shall conduct the assessment prior to dry-out and inform the Employer if the initial cleaning process was unsuccessful.
- F. The Repairer shall recommend options for a successful cleaning, including the following:
 - F.1. A second cleaning process, which will be a repeat of the initial cleaning procedure.
 - F.2. An alternative cleaning method that is suitable for the removal of remaining grime.

3.1.3.5 Motor Dry-out

4.1.3.5.1 Oven Capabilities

A completely cleaned stator shall be dried out in an oven which has the following minimum capabilities:

- A. Time stamped trend recording of the oven dry-out, to be trended throughout the drying process. The time-stamped record of the dry-out process shall be kept and provided to the Employer for record keeping. The oven temperature is to be recorded electronically and not manually. The temperature must be a representative of the highest temperature in the oven.
- B. Drying of the windings is to be done in an oven with temperature range of 90°C - 120°C.
- C. For feedback, the control system shall use air temperature sensors at different locations in the oven to avoid localized overheating.
- D. Motor core and winding temperatures shall also be monitored.

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- E. Hot air circulation is to be by an electric fan or blower.

4.1.3.5.2 Dry-out process

- A. The dry-out process shall be as follows:

- A.1. In order to avoid steam damage, for the first 6 hours the oven temperature shall not exceed the boiling point for water based in the oven environment, i.e. 94°C in Johannesburg.
- A.2. After 6-hours, the oven temperature may be raised but shall not exceed the thermal rating of the stator winding insulation system, including the leads, less 10°C, for the remaining duration of the dry out. As an example for Class F insulated machines with B temperature of 120 °C, the oven temperature shall be set, monitored, recorded and controlled at or below 110°C (120°C -10°C).
- A.3. The motor winding temperatures may also be monitored, recorded, and fed back to the oven control system and not to exceed 90°C.

- B. After dry-out, the IR and PI tests shall be performed to confirm the winding is dry as per subsection 4.4.2.2 Stator Winding Tests. The conditions for the test and acceptance of the motor as being dried out are:

- B.1. The winding shall be within 10°C of ambient temperature before final IR acceptance testing is performed.
- B.2. The dry-out should be considered complete if the previously benchmarked dry IR, as indicated by PI and IR1min, is reached. A compromise consideration may be to deem the dry-out as successful when IR1min and PI measurements show levels higher than the minimum acceptance values in Table 2: Insulation Resistance Test Acceptance Criteria.

4.1.3.6 Post-cleaning Assessment

- A. If any motor component has not been completely inspected and tested as specified during the pre-cleaning assessment, such a component shall have its specified inspection and testing completed after its cleaning and dry-out.
- B. The concentricity of the bearing mounting flanges on the stator frame and bearing housing bores, relative to the stator bore shall be checked and recorded by the Repairer on the motor Assessment Sheet.

4.1.3.7 Phase I Documentation

- A. When a motor is received in a failed condition, all effort must be made to determine the root cause of failure. In the case of uncertainty, all possible root causes are to be listed. Root causes of the failures are to be determined during the various stages of the refurbishment process such as testing, dismantling, etc. Abnormalities that could have contributed to the failure are to be properly recorded.
- B. The Repairer shall compile an incoming *Motor Repair and Refurbishment Assessment Form 240-87739380* and attached tests results of all tests conducted. This form also records the motor design information required by the Employer's Motor System Engineer. The Repairer shall also compile the failure report and repair SOW for each motor that been assessed for repair or overhaul.
- C. The Repairer shall submit the following documents to the Employer:

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- C.1. **Motor Failure report** detailing findings together with photographs identifying the symptoms identified and possible root causes. Recommendation of corrective and preventative actions is to be provided.
- C.2. A fully completed **Motor Repair and Refurbishment Assessment Form 240-87739380**, with all test results to the Employer.
- C.3. A recommended **refurbishment SOW** with associated **itemised cost of repair**.

4.1.3.8 Refurbishment SOW Assessment

4.1.3.8.1 Requirements

- A. The Repairer shall provide the Employer with a recommended **refurbishment SOW** based on the analysis of the failure or overhaul requirement to return the motor to a serviceable condition.
- B. The recommended SOW is governed by the following requirements:
 - B.1. It shall be based on the MV Motor Assessment Form 240-87739380 in APPENDIX B, root cause analysis/failure report and the Employer's input.
 - B.2. It shall be e-mailed to the Employer for review and influence.
 - B.3. The ITP shall also be provided for review and influence.
- C. The Repairer shall provide the delivery date based on the SOW.

4.1.3.8.2 Refurbishment SOW Review

- A. The Employer shall review the recommended SOW considering all documentation provided by the Repairer and inspections conducted and may update the refurbishment SOW that shall be the discussion document at the Repairer site meeting before execution.
- B. The final SOW shall include:
 - B.1. Nameplate and failure assessment details about the motor.
 - B.2. The requirement for the date by which the motor is to be delivered.
- C. The Employer shall evaluate the Repair Vs Replacement as per subsection 4.1.3.9.
- D. Where the repair contract exists, the refurbishment SOW will be reviewed and authorised by the Employer for execution. The refurbishment work shall not start before approval of SOW and ITP.

4.1.3.8.3 Repair & Reconditioning Tasks

As a guideline, the following repair and reconditioning tasks shall be included in the SOW:

- A. All broken or rusty miscellaneous hardware such as nuts, bolts, and washers shall be replaced. New hardware shall be of a similar or better grade to that being replaced.
- B. Repair loose wedging and replace any loose end winding bracing components.
- C. Repair any stator core defects.
- D. Replace any cracked or broken core bolt insulation.

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- E. Missing or defective baffle mounting hardware shall be replaced and mounting bolts shall be locked in place by applying a thread-locker to bolt threads or by other equivalent means to prevent loosening in operation. Air baffle damage shall be repaired.
- F. Rotor core defects shall be repaired as per the discussed repair strategy.
- G. Any rotor fan and/or rotor bar defects shall be repaired.
- H. Cracks in welds are to be repaired.
- I. All rolling-element bearings shall be replaced. Repair bearing housing defects and restore bearing fits in accordance with subsection 4.2.1.4 Bearing Assemblies.
- J. Defective oil rings shall be repaired or replaced. Screws in split oil rings shall be tightened and locked in place by pinning or some other means. If the oil ring viewing port glass in the bearing housing is no longer transparent, it shall be replaced.
- K. Defective bearing insulation shall be replaced.
- L. Defective heater wiring and resistive elements shall be replaced. After such replacement a check shall be carried out to ensure no heater wiring is too close or touching a heater element. Additional space heaters should be installed if excessive corrosion is found to have resulted from the inadequate capacity of the existing heaters.
- M. Coating the insulation system with multiple layers of 'insulating' varnish may be detrimental to the cooling efficiency of the motor. If the stator insulation is found to be in satisfactory condition, an assessment shall be conducted by the Employer to determine if the rotor and stator shall be coated with any form of painting.
- N. Coating or painting of heat exchanger tubes is detrimental to the cooling efficiency of the motor and is not allowed.

4.1.3.9 Repair vs Replacement

- A. The Employer's motor system engineer shall technically and economically evaluate the replacement of failed motors, when one or more of the following conditions are valid:

4.1.3.9.1 Economic Evaluation

- A. The motor requires the replacement of major components such as; the stator windings, rotor cage, stator core, and rotor core.
- B. The failure analysis identifies the failure to be due to latent design defect.
- C. The failure analysis and failure rate of similar motors show that the motors are failing due to ageing, or design unsuitability to application.

4.1.3.9.2 Cost/Benefit Analysis Ratio

- A. The evaluation is to be based on the ratio of cost/benefit analysis using credible and justifiable assumptions. As a basic 'rule of thumb', the recommendation may be based on the cost of the proposed repair work versus the cost for a new motor. A rule of thumb analysis ratio would be as follows:

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- A.1. If the repair cost is less than or equal to 50% of the cost of a new motor, then the motor should be repaired.
- A.2. If the repair cost is above 50% and less or equal to 70%, the Employer needs to assess the motor condition based upon the budget and requirement to return the motor to service.
- A.3. If the cost of repairs is greater than 70% of the accumulated costs, there should be a strong recommendation made to procure a new motor and, if necessary, devise a contingency plan for the station to cater for the lead times of the new motor.
- A.4. If the motor repair history indicates poor reliability of the design, the Employer shall investigate a modification to improve reliability or replace the motor with a suitable design.
- A.5. If the motor has to be replaced, it shall be scrapped as per applicable electric motor scrapping procedures and the replacement motor procured as per Eskom 240-50237155. The Employer may decide to have the motor, which is to be replaced, reconditioned as a spare while the delivery of the replacement motor is awaited. All relevant warranties/guarantees are to be considered to determine Repairer liabilities.

4.2 PHASE II REQUIREMENTS

- A. The motor refurbishment strategy to be utilised shall be determined by the relevant station and shall be agreed upon by the relevant technical personnel, maintenance, material management and the respective commercial department.
- B. Gx Engineering department recommends each station to a full establish a refurbishment contract that covers transport, strip, assess and refurbishment for efficient refurbishment of MV Motors with less risks and delays. Contract splitting to address new and old repairers with limitations can be considered with Employer's system engineer evaluating the risk of critical and non-critical machine refurbishments.

4.2.1 Motor Refurbishment

4.2.1.1 Stator Windings

4.2.1.1.1 Stator Winding Copper and Insulation

If a complete stator rewind is necessary, the following methods and procedures shall be used:

- A. The Repairer shall submit the winding data to the Employer's motor system engineer for verification and acceptance before rewinding. The cross-section area of the strands/wire shall be the same or better than the original winding. The Employer may request additional information to validate the proposed winding design.
- B. Where the winding has to be replaced with the same insulation system winding, the new coils shall have the same number of turns, same number of conductors, same turn and strand insulation, and same conductor cross-section area as the original coils. The thermal rating and thickness of the ground wall insulation shall be the same, or greater than that of the original winding.
- C. The winding information and all proposed changes from the original winding system shall be reviewed and discussed with the Employer's motor system engineer prior to implementation. The Employer reserve the rights to reject the rewind completed without acceptance.

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- D. Conductors shall be of high conductivity copper according to SANS 804 of rectangular section having dimensions, tolerances and corners radiuses according to SANS 600317.
- E. All materials employed in the stator winding system shall be compatible and suitable for continuous operation at a Class F (155°C) hot spot temperature or higher. The combined system of insulating materials shall have been certified as suitable for Class F or higher.
- F. Winding insulation shall be oil resistant & non-hygroscopic.
- G. Conductor insulation is to comply to modern systems of rewinding appropriate with IEC standards. Breakdown, bending and elongation tests on the covered conductor shall conform to the relevant IEC standards.
- H. If stator windings have to be burned out, it is recommended that the stator end-windings are cut-off prior to insulation burn out to facilitate better oven temperature control. The process shall be done in an oven with the following capabilities:
 - H.1. Automatic precision temperature control system that shall use air temperature sensors at different locations in the oven and winding or core temperatures as control system feedback. The core temperature shall be controlled not to exceed 350°C with a tolerance of ±3%.
 - H.2. Time stamped trended recording of the oven burn-out process. The time-stamped record of the burn-out process shall be kept and provided to the Employer for record keeping.
 - H.3. A quenching system (e.g. air or water spray).
- I. If the stator core losses after removing the old winding are 20% greater than the initial pre-stripping core loss, the Employer shall be contacted. The Repairer shall restore the core losses to less than the 20% limit.
- J. All core repairs and testing are to be completed before installing the new winding.
- K. Where replacement coils and bars have a loose fit due to modern insulation types, it is preferred that copper sizes be appropriately increased first to improve the fit. Conductor size may be modified only with the approval of the Employer's engineer having evaluated the modification impact on motor performance parameters, which will have been provided by the Repairer's qualified and appropriately registered Engineer to conduct motor designs.
- L. In general, loose fits between windings in core slots should not be remedied by means of increased insulation. Insulation thickness (conductor and strand) should also not be less than the original design unless improved and proven insulation materials are utilised.
- M. Acceptable materials for use as strand insulation are; double Dacron glass, Nomex 418 and mica tape wrapped or fused over bare copper or Class 180°C and higher enamel, or equivalent.
- N. Based on the required volts/turn capability of conductor insulation, an appropriate number of ½ lapped layers of mica tape shall be used as turn insulation over strands insulated with acceptable materials. Motors rated above 6kV shall have a minimum of two ½ lapped layers of mica tape. Turn insulation shall be reinforced at the coil knuckles and the conductor stacks shall be fully consolidated in the straight sections of the coil legs before application of the ground-wall insulation. Kapton polyamide film is not acceptable as turn insulation material.
- O. Ground-wall insulation requirements include the following:

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- O.1. The new coils must have at least the same number of ½ lap mica tape layers of insulation as the originally taped coils. Mica tape shall be supported by glass cloth, polyester mat, or floc compatible with the VPI epoxy, or polyester resin to ensure proper resin penetration and bonding.
- O.2. Tapes containing polyester (Mylar™), Polyimide (Kapton™), or other films are not acceptable.
- O.3. The ground-wall insulation on the end windings and connections shall have the same number of layers of insulation as the slot portions. If the Repairer is concerned that winding cooling and inter-phase spacing may be compromised, a concession on this issue should be agreed upon between the Repairer and the Employer
- O.4. All windings 6.6kV and above shall have corona suppression applied. Corona suppression tapes may slow the flow of resin into the insulation system during VPI processing and, therefore, require a longer treatment time than normal. All 6.6kV motors and above shall, therefore, be put through the VPI process that is not shorter than that normal for 11kV windings.
- O.5. Corona suppression for 11kV and 15kV windings shall consist of carbon, or graphite semi-conductive tapes applied to the slot sections that shall extend at least 25 mm beyond the end of the core.
- O.6. Silicon carbide grading tape is to be used on the end windings, and this shall overlap the semi-conducting slot section tape and extend to approximately 50 mm past the first bend of each coil.
- O.7. The maximum clearance between the coils and core slots shall be 0.25mm/side.
- P. The stator winding shall have minimum of two embedded temperature detectors (ETDs), thermocouples or RTDs, type PT100 that are either 3-wire or 4-wire, located in the hottest part of each phase winding. Where the hottest part of the winding is not in the middle of the core section, additional ETDs shall be embedded in the middle of the slot between coils of each phase. The ETDs shall have shielded leads and all shall be connected to a terminal strip in the ETD terminal box. The type of ETD shall be as per original design unless it was omitted on original design.
- Q. Materials acceptable for use in end-winding lacing and tying are; heat shrinkable tape, rope, cord, or tie materials made of glass roving. Tapes of 100% Dacron are not allowed.
- R. Acceptable end-winding blocking materials are; epoxy or polyester-saturated Dacron® or Nomex ® felt materials or glass mat.

4.2.1.1.2 Stator Slot Wedging

- A. The under-wedge packers (filler strips) shall be rigid glass epoxy laminates to enable the replacement of wedges without possible damage to the global VPI stator winding insulation. Rigid polyester fibreglass and a felted Nomex ® may also be used as the under-wedge filler to achieve the coil protection and the objective of a secure fit. Use of exclusively soft under-wedge packing material is unacceptable.
- B. Mid slot and bottom packers as well as side packers, if necessary, shall extend at least 13 mm beyond each end of the stator core.
- C. With semi-conductive tape applied to all coil straight portions, filler strips and side packing made of semi-conductive material which has resistivity limits of 1,000 to 10,000 ohms/square shall be used.

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D. Wedges shall be replaced as follows:

- D.1. Wedges shall as far as practicable be replaced with wedges of the same type as the original windings. The wedge material utilised should not substantially change the efficiency of the motor. If the original type is unknown, the preferred wedges are epoxy type wedges. Should magnetic wedges be offered, the Employer is to be provided with written proof that the wedges will provide the expected life. Epoxy Glass laminate type is not acceptable. Replacement wedges shall be bonded with an epoxy resin to the slot, but without causing air-vent blockages.
- D.2. The Employer's motor system engineer is to approve the Repairer wedge removal and replacement procedure prior to the replacement process. Where removal of wedges might pose a risk of damage to the winding insulation, the Employer is to be notified beforehand. Removal of wedges only to be carried out following approval by the Employer's motor system engineer.
- D.3. If more than 10% of the motor wedges are found to be loose, all motor wedges shall be replaced. This is provided the ground wall insulation is not damaged in the process.
- D.4. Special attention shall be given to the accurate tight fitting and wedging of the stator bars. This is to reduce partial discharge and to prevent the bars from vibrating in the slots. Thereby preventing erosion of the corona shield.
- D.5. In order to ensure that wedges have not become dislodged or loose in service, wedges are required to be tight fit and epoxied in place by means of the appropriate epoxy.
- D.6. During the wedge removal or replacement process emphasis is to be placed on:
 - Ensuring that no foreign material is trapped between the wedge and the winding insulation/space/core.
 - Ensuring no damage is done to the core, which may lead to shorted laminations.

4.2.1.1.3 Stator Winding Connections and Pre-VPI Testing

A. All connections between coils, phase rings, and leads are subject to the following:

- A.1. Connections are to be brazed with a material containing at least 15% silver and completely sealed with full ground-wall insulation of mica tape, and a final layer of glass or Dacron® armour tape.
- A.2. Jumpers shall be constructed from copper conductors that have at least the same cross section as those in the coils and shall be insulated with full ground insulation. Dacron® or Nomex® felt spacers shall be used, where needed, to make the connection structure more rigid and provide phase separation. Where possible, additional series connection bracing shall be furnished by tying series connections to a resin impregnated rope.
- A.3. All shall be insulated with the same number of layers of mica tape as the coils.
- A.4. The use of motor lead cables for connections, jumpers, etc., around any part of the end windings, is not acceptable.

B. After connections between coils have been completed, but before the new winding is put through the VPI process, the winding rotation and quality of brazing shall be checked and tested using the power (induction) test. This test, which shall be witnessed by the Employer, and shall have two parts:

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- B.1. The first part shall be to verify correct connection of the winding by supplying adequate power to the winding and using a ball bearing or dummy rotor to ensure that there is proper rotation. The rotor or dummy bearing shall not stop or reverse direction if the connections are correct.
- B.2. The second part shall be to check the brazing joint quality by increasing the voltage supply until the line currents are equal to rated full load current. As the winding warms up, thermal evaluation of the end-windings shall be conducted using an infrared camera. Comparison between coil turns and brazed connections shall be made. Acceptance criterion is that the thermal images of brazed connections shall not exhibit higher temperatures than the coil end-turns.

4.2.1.1.4 Stator Winding VPI Process

The guideline for the VPI process is as follows:

- A. The rewind insulation system for complete form wound windings to be utilised is the global VPI process.
- B. Where the global VPI process is not possible, the Employer's motor system engineer or specialist is required to review and accept the alternative process, prior to the rewind process starting.
- C. Within the global VPI process, preference is to utilise the rotate curing process. This process is to ensure the least amount of separation of resin and insulation during curing. If the resin is viscous enough not to run during curing, the rotating process may be neglected and proof is to be provided.
- D. Data logging is to be carried out throughout the entire VPI process. This includes the initial heating cycle and eventual oven curing. In this way the entire process is reviewed.
- E. A data logging print out generated from an automatic data logging system is to be supplied for review subsequent to the VPI process and prior to final testing. The data logging print out is required to form part of the final report.
- F. Only printed logging sheets generated from an automatic data logging system are acceptable. No handwritten or artificially generated log sheets will be accepted.
- G. As part of the VPI process, the capacitance of the motor is to be measured during the impregnation cycle. This capacitance measurement should be part of the data logging print out. From the printout, it is to be clear that the capacitance has stabilised (resin impregnation is complete).
- H. The VPI process should ensure that the VPI resin is properly degassed prior to the resin filling of the motor tank. Documentation should be provided to the Employer.
- I. The VPI process should ensure that the ventilation/cooling slots, ducts and pipes are not blocked by the resin. Where possible the slots, ducts and pipes are to be inspected for blockages prior to the VPI process and prior to baking. This necessitates sufficient dripping time between the VPI tank and the oven. The motor is to be rotated and re-aligned to ensure maximum resin drainage during the dripping time. The motor is to be positioned in the oven such that maximum drainage is ensured.
- J. Only polyester and epoxy resins are acceptable.
- K. The Repairer shall have a QA&C method of ensuring adequate resin penetration into the conductor before the stator can be removed from the VPI tank for curing.

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- L. The VPI process including time, temperature, and vacuum and pressure values shall conform or exceed the resin vendor's recommendations. Time stamped recording of the VPI process shall be kept for each job and provided to the Employer, when requested.
- M. Each motor rewind shall have at least one sample coil put through the VPI process. Requirements for sample coils are:
 - M.1. The sample coils shall be manufactured in the same process as the motor coils, including the specified corona protection. Both coil slot sections shall be embedded in steel or aluminium channels that simulate the specific motor's stator core portions. If the core does not have air-vents, the slot portion may be wrapped in earthed conducting tape or foil, but steel or aluminium channels are preferred.
 - M.2. At least 1 (one) spare coil shall be fully processed with the motor in the entire VPI and Curing process.
 - M.3. After oven curing, but before any winding testing, the completely processed sample coil shall be subjected to insulation tests. Such tests shall include but is not limited to IR, Tan- δ , and Impulse Voltage tests.
 - M.4. The Employer reserves the right to keep the whole sample coil or portions thereof.

4.2.1.1.5 Stator Winding Leads

- A. Motor lead cables shall be installed after impregnation to prevent ingress of resin during the VPI process.
- B. Requirements for tail leads are:
 - B.1. They shall be rated to carry at least 125% of motor full load current and have an insulating covering that has a thermal rating of 155°C rating or higher.
 - B.2. The preferred cable insulating material is silicone rubber with an outer glass over-braid for mechanical protection. Other types of cable insulation may be used if approved by the Employer's motor system engineer and are to be sleeved with a silicone coated glass braid to protect them from the effects of lubricating oil.
 - B.3. The length shall be at least 1 (one) meter and a slack of at least 500 mm.
 - B.4. The motor leads shall be permanently marked identifying the relevant phase of each. Metal band tagging is not allowed.
 - B.5. Lead spacing and clamping devices shall be used between the winding and terminal box and where the lead cables pass through the stator frame to the terminal box. In this manner the lead cables are to be adequately secured.
 - B.6. The motor lead cables shall not touch any corners or shape of the frame to avoid damage during operation. The lead shall be supported inside the frame by nonconductive materials.
 - B.7. The motor lead lug size shall be equivalent to the original size or better.

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4.2.1.2 Stator Core

4.2.1.2.1 Stator Core Testing and Repair

- A. A stator core loss test shall be performed at the following stages of repair:
- A.1. Before any stator core, or winding repairs are performed.
 - A.2. After removal of the stator winding for replacement.
 - A.3. After stator core, or winding repairs
- B. Where the core testing and inspection indicates a degraded core, this needs to be indicated to the Employer including a recommended repair procedure.
- C. If core inspection and/or testing indicate shorts between laminations, these shall be cleared to obtain a satisfactory core loss test and to eliminate hot spots. The Employer is to authorize any core repair technique.
- C.1. Where hot spots need to be removed by means of grinding/machining, written approval needs to be obtained from the Employer. Re-insulation of the core with materials that have a thermal rating of 540°C or higher may be required after core skimming. A successful core skimming process results in the elimination of hot spots outside of acceptable limits.
 - C.2. Restacking or replacement of the core shall be a solution for deep lamination insulation damage when a stator has to be rewound.
- D. The Employer is to be supplied with a written repair method. The expected impact which the proposed repair method has on the motor efficiency/performance is to be highlighted in the report.
- E. Where it is recommended that the core is to be reused, a repair method is to be provided that will include insulating the laminations such that hot spots are mitigated and prevented as far as possible.
- F. If the core restack is necessary, this shall be done as follows:
- F.1. Prior to the restacking of the core, approval needs to be obtained from the Employer.
 - F.2. The Repairer must make a gauge bar that can be appropriately inserted through each original slot.
 - F.3. Unstack the core, flatten, and de-burr laminations as required. Care must be taken not to damage laminations.
 - F.4. Remove all loose and flaking varnish.
 - F.5. Coat at least one side of each lamination with a uniform layer of acceptable insulation material. Excessive insulating material build-up and runs must be avoided.
 - F.6. Dry coated laminations in an oven for coating to cure and provide the best possible uniformity for stacking.
 - F.7. To ensure uniformity, parallelism, and correct sizing of the slots, careful control of the stacking process is mandatory. Such control includes the following actions and requirements:
 - During the stacking process, press the core stack at a minimum of one third of the core length and check the slot dimensions to be within the original dimensions.
 - The gauge bar must be inserted to check the slot dimensions.

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- Grinding of the slots or dovetails to correct the slot dimensions is not allowed. If the gauge bar cannot be inserted, the core restack shall be re-started.
- The final core length must be equal to the original core length. The only allowed tolerance is 0% to -0.5%.
- The restacked core must be located within the frame to prevent rotor magnetic centre shift.
- It should not be possible to insert a 0.5mm filler gauge between any laminations.
- No area of the core may build up heat outside the acceptance criteria after restacking is complete.

G. Loose core clamping-fingers or duct-spacers should be tightened or replaced.

H. Damaged core through-bolt insulation shall be replaced.

I. The repair method is to include particulars of all replacement materials. Deviations from original specifications are to be clearly indicated to the Employer. The following information is to be included in the documented repair method:

I.1. Thickness

I.2. Watt per kilogram loss at 50 Hz

I.3. RMS exciting current

4.2.1.2.2 Stator Core Replacement

Core replacement is subject to the following requirements:

- A. Core replacement material is required to match the original component dimensions of the motor. Material specifications are to be the same or an improvement of the original specifications.
- B. The Repairer shall provide the thickness, Magnetization losses (W/kg) at 50 Hz, and exciting currents for both original and new laminations.
- C. Replacement core laminations shall be of the same size and shape as the original laminations but may be made of higher grade of steel.
- D. New laminations must be burr free.
- E. Magnetization losses (W/kg) at 50 Hz and exciting current of replacement laminations shall not exceed values of the original laminations.
- F. "Short-stacking" or providing less than original core length is not permitted.
- G. Cooling air vents shall be restored to original dimensions and locations.

4.2.1.3 Rotor

4.2.1.3.1 Rotor cage repair

All repairs on the rotor cages shall be conducted as follows:

- A. If the assessment shows any cracked or broken bar, or broken shorting rings, or complete cage migration in one direction, the cage shall be replaced with material of the same size, grade and

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conductivity. Metallurgical and conductivity tests shall be performed on original and new bar and ring materials to confirm compatibility with the original rotor specifications.

- B. Broken bar-to-shortring ring or shorting ring joints may be repaired. Rolled shorting rings with broken joints shall be replaced by a single piece forged or cast rings. The complete shorting ring shall be removed and all matting surfaces on bars and single piece forged rings cleaned before re-brazing the joints.
- C. If loose bars are found, but are not broken or cracked, the Repairer shall recommend a method of tightening the bars for acceptance by the Employer's motor system engineer. Dipping and baking the rotor in epoxy, polyester, or any other type of resin or varnish is not an acceptable repair method for loose bars.
- D. If die-cast aluminium rotor bars are found to have deep cracks, or breaks, the complete rotor shall be replaced. Replacement of die-cast rotor cage windings with fabricated types is not acceptable.
- E. If the core damage is not too extensive, skimming the rotor in a lathe with a sharp tool should eliminate surface smearing. Such repairs shall not increase the stator-to-rotor air gap by more than 10% and should only be performed once in the life of the rotor core. Acid etching or high-speed grinding may be used to repair localized damage.
- F. Rotor winding joint repairs shall be checked for defects using one of the specified test techniques as per the section Inspection and Testing.
- G. Rotor core laminations damaged due to broken rotor bars, looseness, or any other cause, shall be considered for replacement if extensive.
- H. Loose and missing duct spacers and end fingers shall be fixed in-place by spot welding.

4.2.1.3.2 Journals, mounting surfaces and shaft extensions.

Repairs on friction type bearing journals, ball and roller bearing mounting surfaces, seal surfaces and shaft extensions shall be conducted as follows:

- A. Superficial damage can be polished up with a microfiber cloth.
- B. More severe damage requires the correct shaft diameter and surface finish to be restored as follows:
 - B.1. Remove the damage by machining followed by rebuilding with micro-welding,
 - B.2. Grind the surface to restore shaft diameter to correct dimensions and surface finish as follows:
 - Bearing journals – 410 µmm, or better
 - Rolling element bearing mounting surfaces – 810 µmm, or better
 - Thrust runner, or bearing hub mounting surfaces – 810 µmm, or better.
 - Shaft extensions – 810 µmm, or better
 - Bearing seal surfaces – 1625 µmm, or better
- C. Metal spraying is not allowed.
- D. **NDT shall be performed on repaired shafts** in order to requalify the shaft for extended use.

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4.2.1.3.3 Shaft Replacements

Bent shafts that cannot be straightened or cracked or broken shafts shall be replaced as follows:

- A. Record all critical shaft dimensions relative to one shoulder prior to the start of shaft removal.
- B. Tighten the core, if necessary, before the shaft is removed.
- C. Remove all shafts, except for 2-pole motors with fabricated rotors, by pressing them out of the cage.
- D. The Repairer shall obtain OEM information on the existing shaft material if the Employer cannot provide such information. If the shaft design information is not available, tests shall be conducted on the old shaft to determine its material properties, including hardness.
- E. Select and confirm the new shaft material to have properties that are similar to that of the old shaft.
- F. Machine all shaft steps, including keyways, to incorporate appropriate radii to avoid stress concentrations.
- G. Shrink fit the shaft into the core.
- H. Check and ensure concentricity of the shaft with the core outside diameter.
- I. Perform final shaft machining.
- J. Spider arm weld cracks that have been verified by dye penetrant tests require grinding and welding repair if grinding cannot eliminate surface cracks.
- K. Cracked cooling air fans shall be replaced and loose components, such as those used for balancing, shall be welded. If the fan is hub mounted and the mounting is found to be loose, the shaft OD, or hub bore shall be built up to restore an interference fit of 0.125 mm. per mm of shaft diameter. Any damaged keys, or keyways used to connect a fan hub to the rotor shaft shall be repaired.
- L. Rotor balance check as per the section Inspection and Tests shall be performed on all motors being reconditioned or repaired after rotor cleaning and after any rotor repairs.

4.2.1.4 Bearing Assemblies

4.2.1.4.1 Anti-friction Bearings

- A. Anti-friction bearings shall not be repaired and shall be replaced during motor reconditioning and/or repairs that involve disassembly.
- B. Anti-friction bearings are to be inspected for abnormalities and the Employer is to be provided with a report of the findings.
- C. The following procedures shall be followed when installing new rolling element bearings:
 - C.1. The bearings shall have metal cages complying with ISO/15:1998 with radial clearance of C3 (3dot).
 - C.2. During bearing installation, heating shall be within the tolerances laid down in the relevant bearing manual and shall not exceed 110°C. This takes place using an induction heater with a demagnetizing facility. This is also relevant where bearings are removed with the intention of putting it back in service.
 - C.3. The use of used bearings is not permitted unless it has been so instructed by the Employer.

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- C.4. Bearing housings shall be checked dimensionally and for concentricity to ensure the required tolerances are met as specified in the bearing selection and maintenance manuals.
- C.5. Tolerances are as follows:
- Ball Bearings - J6
 - Roller Bearings - K6
- C.6. The new grease-lubricated bearing should be packed with the type and grade of grease specified in the motor nameplate data or as specified by the Employer.
- C.7. During installation, the bearing must be pushed on to the shaft or mounting hub by its inner race.
- C.8. Unless the motor manufacturer or experience indicates otherwise, the bearing housings shall be 2/3 packed with new grease of the type specified.
- C.9. Bearing housings with oversized bores shall be bored out, sleeved and machined to restore the correct bearing outer ring-to-housing fit. The bearing housing wall thickness shall not be reduced by more than 25% during such repairs.
- C.10. Out-of-tolerance bearing housing axial clearances shall be corrected by machining, or by replacing bearing assembly components.
- C.11. Plain seal clearances between the shaft and bearing housing can be restored by boring and re-sleeving the housing. Non-metallic bearing housing seals shall be replaced and labyrinth type seals either repaired or replaced.
- C.12. If the bearing hub-to-shaft fit is too loose, it shall be corrected by either restoring the shaft dimensions to specification or by manufacturing a new hub to specifications or by a combination of the two.

4.2.1.4.2 Sleeve and Tilting Pad Bearings

The following procedures shall be followed when reconditioning or repairing sleeve and tilting pad bearing assemblies:

- A. With the bearing shells installed, bearings shall be checked for tolerances, concentricity and nip. On fitting of the rotor into the stator, bearing clearances and lay shall be checked to ensure correct fitting of the shell.
- B. Blueing and plastic gauges are to be used if the lay is not greater than 90%. The responsible engineer is to be contacted for permission before any scrapping takes place. With the modern manufacturing techniques, scrapping should not be necessary. All joints, inlets, drain plugs etc. shall be sealed to prevent oil leaks. Copies of the blueprints are to be provided as part of data pack, together with copies of the measured bearing tolerances.
- C. Minor white metal scratches shall be repaired by polishing the damaged surfaces with a polishing pad such as Scotch-brite® cloth. Tilting pad bearings shall have their minor scratches lapped or rubbed with Scotch-brite® to remove high points.
- D. Major scoring and wipes on the white metal surfaces shall be repaired by replacing or re-metalling the bearing. If the bearing needs to be re-metalled or replaced, an ultrasonic test shall be conducted

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on the re-metalled or replacement bearing white metal before bearing installation. The pads for tilting pad bearings shall be replaced or re-metalled as a complete set. The acceptance criterion for such testing is at least 95% bonding over the journal area and 100% bonding on the edges.

- E. Out-of-tolerance bearing housings shall be machined if under size or built up if over size.
- F. Damage or excessive clearances in labyrinth seals shall be corrected by repair, or replacement of the seals. If the motor manufacturer's seal design clearances are not available, the diametrical clearances shall be restored to values that are 0.0508mm to 0.1016mm greater than the bearing clearance.
- G. Oil rings and pick-up discs shall be checked for roundness and wear. Damaged oil rings in sleeve bearings shall be replaced. If the ring is a split ring, the screw holding the two halves of the ring together shall be tightened and locked in place by pinning or some other means. A dye-penetration test is to be conducted on each split half of the ring to determine the existence of cracks.
- H. Unless the bearing is specifically designed for a double oil ring, all double oil rings are to be replaced with a single oil ring.
- I. Replace any oil ring sight glass that is no longer transparent or has some other defect.
- J. If the thrust runner-to-shaft fit is too loose, restore the shaft dimensions by plating and/or micro-welding the hub bore and machining it for the desired dimensions. Machining and lapping procedures may be used to restore thrust bearing thrust runner surfaces. Alternatively, a new thrust runner may be manufactured with correct dimensions.
- K. Any sediment, metal particles, or other contaminants shall be removed from the oil reservoir with a dry, lint free, cloth.
- L. Oil reservoirs shall be leak-checked after necessary repairs and final inspections have been completed. To test for leaks, fill the reservoir with a low viscosity cleaning fluid such as Varsol® and inspect external surfaces and connections. After leak tests, Varsol® shall be drained and any remaining residue shall be removed by wiping with a dry, lint free, cloth.
- M. The oil reservoir shall be thoroughly cleaned of oil and grease and painted with a white, two-part, epoxy.
- N. Any debris trapped between cooler fins shall be removed.
- O. If leaks are present, or if there is thinning of the bearing cooler tube walls, the cooler shall be replaced with a new cooler. If the failure mechanism is found to be erosion/ corrosion, a better corrosion resistant material such as stainless steel should be considered for the replacement. All repaired, or replacement coolers shall be pressure tested.
- P. Replace all damaged bearing insulation components including insulating sleeves, washers, bearing anti-rotation pins with new components made from NEMA G10 or G11, or equivalent, epoxy glass material.

4.2.1.4.3 Grease relief systems

The following is applicable for bearing grease relief systems:

- A. If no grease release system exists on the bearings, the Repairer shall provide the Employer with a proposal for approval. The Repairer will implement the approved solution.

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- B. Grease release systems should be designed to ensure grease is not discharged inside the motor, the motor fan or slip-ring enclosures.
- C. Extended grease nipples are to be installed where applicable.

4.2.1.4.4 Water Cooled Bearings

The following is applicable to water cooled bearings:

- A. The cooling coil and cooling water jackets shall be cleaned and checked for blockages. New gaskets are to be fitted and pressure is to be checked for leakages.
- B. Cleaning of the cooling coils is to be performed by means of an appropriate method. Chemical cleaning is preferred.

4.2.1.4.5 Oil Gauge Glasses

The following is applicable to oil gauge glasses:

- A. Oil gauge glasses are to be inspected for correct functionality.
- B. Gauge glasses are to be replaced at the sign of cracking.
- C. All leaks are to be repaired by replacing the relevant seals and O-rings.
- D. Oil levels are to be properly and correctly indicated on the oil sight glasses. Indications are to include standing and running oil levels.
- E. Oil level markings on any original gauge glasses are to be verified for correctness. Markings are to preferably indicate both minimum and maximum oil levels.

4.2.1.4.6 Thrust Bearings

The following is applicable to thrust bearings:

- A. The removal of the thrust collar shall be carried out by hydraulic methods. Heat shall not be applied to the thrust collars, directly or indirectly, during removal or fitting. Refitting shall take place in a similar fashion. The run-out of guide and thrust faces is to be checked to ensure correctness.
- B. The thrust collar shall not be rested on the thrust face without adequate protection. Surface finishes of thrust guide faces are to comply with the manufacturer's tolerances.

Note: Bearing manufacturer specified minimum running speeds and run down times is to be adhered to.

4.2.1.5 Accessories

- A. All failed space heater elements shall be replaced with new elements with the same Wattage, Voltage, and surface temperature rating. Unless otherwise agreed between the Repairer and Employer, new space heaters shall be rated to operate at half their rated voltage and connected in parallel.
- B. All damaged or aged heater wiring shall be replaced with high temperature insulated wires, with the same or increased conductor size.
- C. Rewired space heater circuits shall be checked to verify conformance to original circuit configuration.

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- D. All damaged bearing RTD wiring shall be replaced, provided the RTD element indicates the correct temperature.
- E. After repairs, bearing temperature detectors shall be checked for accuracy.

4.2.2 Motor Assembly

- A. All tests and inspections conducted as part of the motor assembly shall be recorded on a motor build report. The procedure for these checks and tests during motor assembly are contained in the section Inspection and Testing.
- B. General requirements are as follows:
 - B.1. Secure bolts by coating threads with a durable anti-corrosion/anti-seize compound. All bolts installed during assembly of motor components or motor component attachments shall be tensioned with proper bolt stretch via torque wrench or other acceptable means.
 - B.2. Clean conditions shall be practiced ensuring that no foreign materials are left inside the motor. Shaft landing surfaces shall be protected from damage due to mishandling.
 - B.3. Care should be taken when assembling bearing cooler pipe connections to prevent twisting the cooler inside the oil reservoir.
 - B.4. The concentricity of bearing bracket mounting flanges, bearing brackets and bearing housing bores shall be checked in relation to the stator bore.
 - B.5. Measure the amount of rotor lift on Vertical Motors with tilting pad bearings.
 - B.6. Fill each bearing with the type and grade of oil specified. Check that the standing oil level is clear and oil is clearly visible on all its site glasses. Oil leaks before, during, and after motor testing are not allowed.
 - B.7. Conduct a **no-load test** on all motors as per subsection 4.4.5 Routine Test.
 - B.8. A **full load performance test** shall be performed on any the motor that has been rewound (stator or rotor rewound) as per the performance procedure.

4.2.3 Painting

Painting shall be done in accordance with the following procedure:

- A. Surface preparation shall involve the removal of all corrosion, oil, grease, dirt, and old paint with a combination of commercially accepted cleaning agents, abrasive blasting, power tool and hand tool cleaning. Metal surfaces shall have sufficient roughness to provide proper adhesion of new paint.
- B. At least one primer coat and two finishing coats of compatible outdoor paint shall be applied in accordance with the paint manufacturer's instructions. Two-part epoxy type paint is preferred because of its toughness and durability.
- C. The finishing colour for external metal surfaces shall be Emerald Grey (G29) or other as specified.

4.2.4 Repaired Motor Delivery

- A. All motors shall be prepared for delivery as per the SOW and Eskom 240-56361435. If the motor is to be sent into storage, such shall be in accordance with Eskom 240-56360387.

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B. The following is required:

- B.1. Motors shall be delivered to site after the Employer's acceptance that the repair SOW has been satisfactorily completed. Any motor delivered before the Repairer receives confirmation of acceptance may, at the Employer's discretion, be returned to the Repairer without any cost to the Employer.
- B.2. The Repairer shall arrange a motor delivery date, time, and location with the Employer.
- B.3. All documentation regarding work performed on the motor shall be delivered with the motor. Documentation shall include reports of results for all tests performed, whether the tests are specifically required within this document or not.
- B.4. The Employer reserves the right to inspect the motor and transport upon delivery and, if the delivery is found not to be in accordance with applicable specifications, return the motor to the Repairer without any costs to the Employer.
- B.5. The Employer shall provide necessary resources for the motor to be off-loaded from the Repairer's transport.

4.2.5 Phase II Documentation

A. The Repairer shall submit the following documents to the Employer:

- A.1. Test report or certificate for components
 - A.1.1. Heat exchanger pressure tests
 - A.1.2. Bearing dimensions and clearances
 - A.1.3. Rotor balancing
 - A.1.4. Bearing Journal and Shaft extension runouts
 - A.1.5. Shaft axial float and magnetic centre
 - A.1.6. Air gap measurements
 - A.1.7. Rotor, Shaft and Fan NDT Tests
- A.2. A fully completed **Motor Repair and Refurbishment Assessment Form 240-87739380**, with all test results to the Employer.
- A.3. Routine test report .
 - A.3.1. Stator winding IR, PI, Winding resistance
 - A.3.2. Insulation resistance for heaters and bearings
 - A.3.3. Resistance for winding RTD/Thermocouples and heaters.
 - A.3.4. Core loss test and hot spot images
 - A.3.5. Roter Elcid and Bar to Bar test
 - A.3.6. Bearing temperature measurements
 - A.3.7. Winding temperature measurements
 - A.3.8. Interturn surge test

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A.3.9. Vibration spectrum report

A.3.10. No-load currents

A.3.11. Shaft voltage measurement

A.3.12. Motor Run down time

A.3.13. Temperature rise where performance test is done

A.4. Signed QCP ITP

4.3 EMERGENCY REPAIRS

- A. The requirements of the normal repair procedure are applicable to emergency repairs, the difference being the duration for the requirements to be fulfilled.
- B. The Employer may classify the motor to require emergency repairs. Having classified that the motor requires emergency repairs, the motor repair/ refurbishment strategy to be utilised shall be determined by the relevant Business Unit and shall be agreed upon by the relevant technical personnel, the end users and the respective commercial departments.

4.4 INSPECTION AND TESTING

- A. Tests and checks shall be performed in accordance with applicable sections in the two phases of repair. If certain results are unacceptable, the Repairer shall notify the Employer to discuss viable solutions.
 - A.1. During the course of repair, the *Employer* may inspect the work at hand to ensure the methods and materials employed are satisfactory. The relevant QCP is to include agreed test criteria, hold points and inspection points.
 - A.2. On completion of work, the machine shall be inspected and tested by the Repairer to the satisfaction and requirements of the Employer. ***Prior to contacting the Employer to arrange a date for witness testing, the Repairer shall have satisfied the Employer's requirements of a successful refurbishment/repair.***
 - A.3. Appropriately qualified personnel are to be used for diagnostic testing, inspections and report compilation. The reports are to form part of the quality documentation for the repair.

4.4.1 Test Reports

- A. Motor test results shall be recorded on the Employer's standard forms for routine tests and performance tests as specified in Eskom Standard 240-50237155 Appendix E and Appendix F. Repairer may use their own standard report forms, but the forms must be amended or supplemented, as needed, to clearly and completely cover any reporting items required by the Employer's standard forms. Use of Repairer standard forms shall be approved by the Employer.
- B. The Repairer's test reports shall include the results of all tests performed, whether the tests are specifically required herein or not.

4.4.2 Electrical Tests

- A. It should be noted that some of the tests listed below are only required if specified in the SOW.

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- B. Minimum requirement for testing equipment is listed in APPENDIX D.

4.4.2.1 Safety precautions

The following precautions shall be observed when conducting electrical tests.

- A. Ensure that the stator windings are completely discharged prior to conducting any electrical test. It is not safe to begin testing before the discharge current is zero and there is no discernible return voltage (less than approximately 20 V) after the ground is removed from the stator. After completion of the test, the winding should be discharged through a suitable resistor, sized to limit the instantaneous current to 1 A.
- B. The leads between the test set and winding must be appropriately insulated and spaced from ground. To avoid measuring stray currents, the leads may be shielded.

4.4.2.2 Stator Winding Tests

4.4.2.2.1 Insulation Resistance (IR) and Polarization Index (PI) Tests

- A. Insulation Resistance (IR) tests shall be conducted with a capable megohm meter equipment which will on output provide a plotted trend of the measured insulation resistance as a function of time, throughout the entire duration of the measurement of the IR1min and IR10min. From the trend the Dielectric Absorption Ratio (DAR) and Polarization Index (PI) will be calculated by measuring and recording the 30-second reading (IR30sec), 1-minute reading (IR1min), and 10-minute reading (IR10min). The DC megohm meter shall be capable of developing and displaying test voltages sampled at no longer than 5-second intervals. Test voltages for motors within stated range of rated line-line voltages for 3-phase, line-to-ground for single phase, and direct voltage for DC or field windings are recommended in Table 1.

Table 1: Recommended Insulation Tester Voltages

Motor Rated AC Voltage [V]	DC Test Voltage [V]
V < 1000	500
1000 ≥ V ≤ 2500	1000
2500 > V ≤ 5000	2500
5000 > V ≤ 12000	5000
V > 12000	10000

- B. Ensure that the winding temperature is above ambient air dew point. If the dew point cannot be determined, this test should be conducted when the winding temperature is at or above that of ambient air.
- C. Document the following test conditions:
- C.1. Ambient temperature,
 - C.2. relative humidity,
 - C.3. dew point,
 - C.4. stator winding temperature, and

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C.5. test voltage, as per Table 1.

- D. Each phase should be isolated and tested separately with the other phases grounded, where possible.
- E. Insulation resistance readings are to be taken after applying the test voltage as indicated in Table 1. IR1min is to be temperature corrected to a common base of 40°C using the following equation:

$$R_c = K_t \times R_t$$

where,

R_c = Insulation resistance corrected to 40°C,

R_t = Insulation resistance at Temperature t°C, and

K_t = Insulation resistance temperature coefficient at temperature t°C obtained from Figure 1

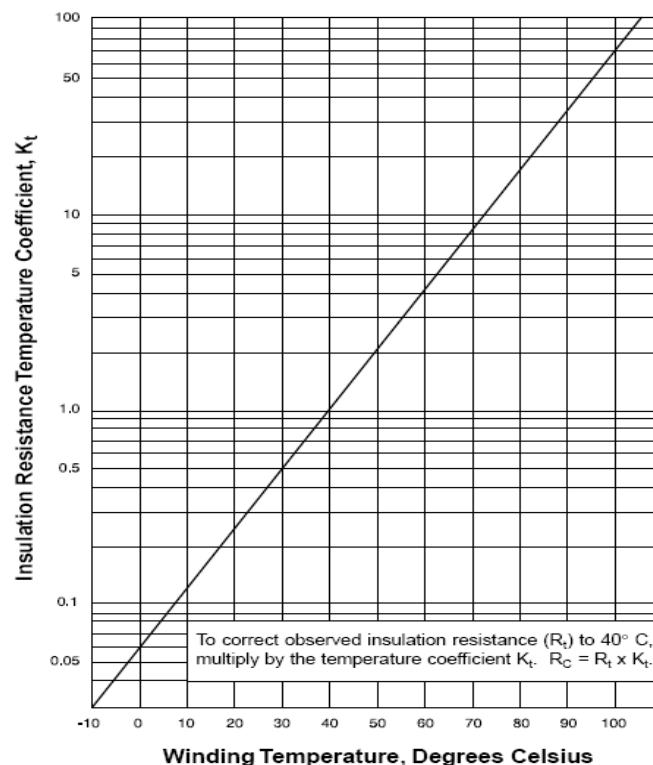


Figure 1: Insulation Resistance Temperature Correction

- F. Table 2 provides guidance for conducting the DC insulation resistance test and acceptance criteria. It shows the minimum corrected IR1 values applicable to all phases-to-earth (entire winding). Minimum IR1 on one phase-to-earth, with the other two phases earthed, should be double that of the entire winding.

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Table 2: Insulation Resistance Test Acceptance Criteria

Motor Rated Voltage [V] ⁽¹⁾	Pre-1970 Winding Minimum IR ₁ @ 40°C [MΩ]	Modern Form-Wound Winding Minimum IR ₁ @ 40°C [MΩ] ⁽⁴⁾	Minimum PI ⁽²⁾	Minimum DAR ⁽³⁾
< 1000	kV+1 ⁽⁵⁾	5	2.0	1.5
3 300		100		
6 600				
11 000				
15 000				
<u>Notes:</u>				
1) The motor rated voltage is based on Eskom standard line to line voltages.				
2) The Polarisation Index, $PI = \frac{IR_{10}}{IR_1}$ - PI shall be disregarded if the corrected IR₁ is above 5 GΩ for modern form-wound windings. - High PI is indicative of thermal deterioration on pre-1970 windings typically made of asphaltic mica insulation.				
3) The Dielectric Absorption Ratio, $DAR = \frac{IR_1}{IR_{30}}$ is the quicker version of PI.				
4) For insulation that consists of mica paper tapes bonded with epoxy resin.				
5) Applicable to most windings made before 1970				

4.4.2.2.2 Stator Winding Resistance Test

The following is required for stator winding resistance tests:

- A bridge-type instrument or digital ohmmeter capable of measuring and displaying milliohms shall be used to record the three-line terminal-to-terminal stator winding DC resistance values, i.e., RUV, RVW and RWU. Letters U-V-W may be substituted by A-B-C, depending on the terminal notation.
- Document the stator winding temperature during the test.
- Correct the measured values to 20°C using the following equation:

$$R_{LL,20} = \left(\frac{R_{LL,T}}{(1 + 0.00392(T - 20))} \right) \Omega$$

where;

$R_{LL,20}$ is the terminal-to-terminal winding resistance correct to 20°C,

$R_{LL,t}$ is the measured terminal-to-terminal winding resistance at t°C,

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- D. Calculate the percentage DC resistance imbalance ($R_{imb.}$) using the following equation:

$$R_{imb.} = \left(\frac{R_{Max. Deviation From Average} - R_{Average}}{R_{Average}} \right) \times 100\%$$

- E. The acceptance criterion for a new winding is that $R_{imb.}$ should not exceed 1.0%. If this value is exceeded clearance should be obtained from the Employer to determine a method to proceed.
- F. Motors with either duplicate or parallel winding terminals shall have the winding resistances measured on one terminal box with all internally connected line terminals on the two terminal boxes shorted to each other, e.g. U1-1 shorted to U1-2, with leads between the two terminal boxes. This method of measurement shall prove the correct phasing of internal line terminal connection between the terminal boxes.
- F.1. Deviation from winding resistances measured without external terminal short circuiting and/or imbalance above acceptance criterion is indicative of incorrect phasing on internal line terminations.

4.4.2.2.3 AC High Potential Test

- A. The Hi-pot test is to be performed upon written request. All AC Hi-pot tests shall be witnessed by the Employer.
- B. The high-voltage test procedure shall comply with IEC Standard 60034-1.
- C. A 50 Hz AC Hi-pot shall always be performed after a motor rewind. Reconditioned windings may, when specified by the Employer, be conducted.
- D. The test shall be performed on either the complete stator winding or individual phase windings. Unless otherwise specified in the SOW, only one of the two methods shall be used. Where the star point is accessible, it shall be disconnected for the individual phase windings to be tested with the other two grounded.
- E. The stator frame and winding temperature detectors, if fitted, shall be grounded before performing the test.
- F. Hi-pot testing shall be performed only after the IR and PI tests have been successfully conducted.
- G. It is the Repairer's responsibility to determine the minimum AC Hi-pot test set kVA rating based upon the capacitance of the winding.
- H. The applied test voltage for an AC Hi-pot test shall be as follows:
- H.1. $(1.5 \times V_{LL})$ for 1.0 minute on reconditioned and repaired old windings, i.e. 4950 V on 3300 V and 16500 V on 11000 V windings.
- H.2. $(2 \times V_{LL} + 1000 \text{ V})$ for 1.0 minute on new windings, i.e. 7600 V on 3300 V and 23000 V on 11000 V windings.
- I. Perform IR and PI tests after the AC Hi-pot test to verify the insulation system was not damaged during the test.

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- J. If the stator fails the AC Hi-pot test after a rewind, the new winding shall be completely replaced with a properly processed winding. All expenses involved with replacing the newly rewound stator shall be the responsibility of Repairer.
- K. For motors with internally connected windings, which have only three line-ends accessible, a single high voltage test shall be applied between the windings and the earthed frame.
- L. For motors having both ends of each phase winding brought out to accessible terminals, the test voltage shall be applied between each phase and earth, with the phases not under test also connected to earth.
- M. For motors in service, the test is to be performed at line voltage for star connected motors.

4.4.2.2.4 DC High Potential Test

- A. The DC hi-pot test is an alternative test to AC hi-pot that shall be performed after a rewind and repair. All requirements for AC hi-pot are applicable to the alternative DC Hi-pot test, with the following exceptions:
 - A.1. Reconditioned windings shall, when specified by the *Employer*, be tested using the DC Step Voltage Test described in the next section.
 - A.2. The applied test voltage for DC Hi-pot test shall be:

$$1.7 \times (2 \times V_{LL} + 1000 \text{ V})$$
 for 1.0 minute on new windings, e.g. 12920 V on 3300 V and 39100 V on 11000 V windings.

4.4.2.2.5 DC Step Voltage Test

- A. The DC Step Voltage test is to be performed upon request of the Employer. All requirements for DC hi-pot are applicable to the DC Step Voltage test, with the following exceptions:
 - A.1. Plot the leakage current versus applied voltage on a graph. An uncontaminated and/or undamaged insulation system has an almost linear curve that should develop as voltage is ramped or stepped up to the final value given in Table 3 below.

Table 3: Recommended DC Step Voltages

Motor Rated Voltage	First DC Step Voltage	Voltage Steps after Initial Step Voltage	Number of Steps	Final 1.0 Minute DC Hipot Voltage	Final Hipot Value as % of DC Equivalent of Motor Rated Voltage*
3300	2000	600	9	8700	155.1%
6600	5000	1500	8	17000	151.5%
11000	10000	2000	9	28000	149.7%
15 000	14000	2500	8	38000	149.0%

* Equivalent DC voltage = $1.7 \times \text{AC value}$

- A.2. If the leakage current increase is rapid and non-linear with respect to applied voltage, stop the test immediately and prior to reaching the final test voltage. This indicates that the motor either requires cleaning and dry-out or it has a ground insulation defect.

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- A.3. After cleaning and drying, repeat the IR and the DC Step Voltage tests. If the DC Step Voltage test cannot be passed after cleaning and drying the windings, the ground insulation defect shall be investigated.

4.4.2.2.6 Impulse Testing

- A. All the stator coils of motors which have been completely rewound shall be subjected to inter-turn insulation tests. All coils installed in the stator shall have interturn insulation surge/impulse tested in accordance with IEEE Std 522, while tests conducted on sample coils shall be conducted in accordance with SANS IEC 60034-15.
- A.1. A type test on a sample coil after inserting it into the stator slots. This coil shall be subjected to four impulses at voltages having peak values of 1kV, 2 x VL and 4x VL (where VL = rated line voltage). The pulse traces should all have the same pattern.
- A.2. Routine tests should then be carried out on all coils after inserting and wedging them into the stator slots. Each coil shall be subjected to 4 impulses having peak values of 2 x VL. The pulse trace in each case shall be compared with the pulse trace obtained for the type test at 1kV. If a difference is observed, a 1kV impulse should be applied to the coil in question. If the difference is still observed, the coil shall be replaced.
- A.3. The impulse wave shall have a maximum rise time of 0,2µs and compliance to this requirement is to be checked by an Eskom approved testing authority.
- A.4. Inter-turn insulation tests are to be performed on old insulation during the initial assessment of a motor.

4.4.2.2.7 Dissipation Factor (Tan-δ) and Capacitance Tests

- A. Tan Delta tests shall be conducted on each winding insulation by measuring and recording power/dissipation factor and capacitance, while the other two phases are shorted to ground, for a completely cured windings. An appropriate size 50 Hz AC test unit to provide the required measurements at applied voltage from 20% to 100%, at 20% increments of motor rated line-to-line voltage shall be utilised. The accuracy of the bridge shall be, at worst, 1%.
- B. Test conditions that are to be recorded are; ambient temperature, relative humidity, stator winding temperature, and test voltage at each test point.
- C. The characteristics to be calculated and evaluated for each winding are;
- C.1. Tan-δ at 20% and 100% of rated voltage,
- C.2. The change in Tan-δ (Δ Tan-δ) between two incremental points from 20% through to 100%,
- C.3. Tan-δ Slope (Tip-up) value from the 20% and 60% voltage points, and
- C.4. The change in Capacitance (Δ C) between the 20% and 100% voltage data points.
- D. The acceptance criteria are as detailed in the Table 4 below.

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Table 4: Tan-δ Acceptance Criteria

Item	For individual phases and total winding	For new windings *	For motors in use **
1	0,2Un Tan Delta value	Less than 0,0100	Less than 0,0400
2	1Un Tan Delta value	Less than 0,0300	Less than 0,0800
3	Steps between 0,2Un to 1Un	Less than 0,0060	Less than 0,0100
4	Slope (0,6Un – 0,2Un) / 2	Less than 0,0060	Less than 0,0100
5	Maximum capacitances change 0,2 Un to 1 Un, with 0,2 Un as reference	Less than 3%	Less than 6%
6	Tip up (1Un – 0,2Un)	Less than 0,0200	Less than 0,0400

NB – Tan-δ values stipulated are to be treated as guidelines.

Note:

* It is accepted that the tan- δ acceptance criteria for a specific motor is dependent on factors such as insulation type and motor design. In the event that the *Repairer* is not capable of meeting the criteria specified in Table 4, agreement on acceptance criteria is to be reached prior to commencing with the rewind process. In the event an agreement is not reached the integrity of the rewind process is to be confirmed by means of a motorette. The following will be applicable to the motorette;

- Motorette to be a randomly selected coil from the set of coils manufactured for the motor.
- Motorette installation into the core simulator is to be the same as the installation into the motor. This includes material dimensions and type, slot liner, packers, spacers, etc.
- Core simulator is to have the same dimensions i.e. length, width and depth as the core.
- Core simulator slot width to be within ± 0.05 mm of the core dimensions with the length within 1,0 mm and depth within 0.5mm.
- Cooling slots are to be simulated by cut-outs in the core simulator.
- Wedge materials are to be strapped in place.
- Both sides of the motorette are to be inserted into the core simulator.
- If the machine is manufactured from bars instead of coils, one bar only is acceptable as a motorette.
- Motorette is to accompany the motor throughout the VPI process to ensure similar VPI exposure.
- Rotate curing of the motorette is not a requirement.
- Motorette can be positioned vertically or horizontally in the VPI tank. The orientation is to be the same as the VPI'd machine. When horizontally positioned, the motorette is to be placed as high as possible in the VPI tank.

** Acceptance criterion for motors in service is NOT a criterion for the failure of the insulation system and is NOT intended to serve as an indication of insulation life. Tan- δ readings are required to be trended over time to determine ageing of insulation. Cognisance is to be taken of the insulation state, type and age.

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4.4.2.3 Core Flux Test

The iron cores of all stators and rotors being repaired, replaced or rewound shall be subjected by the *Repairer* to a core flux test.

- A. Unless otherwise specified or approved, the test shall be performed before and after an unwound core is wound and before and after a wound core is unwound. The test shall also be performed by applying a test voltage which will generate a 1,5T flux density at the back of the core. The Repair must provide the required V/turn for the test.
- B. The core shall be examined for abnormal or uneven heating (hot spots) by means of a thermal camera. Hot spots are any spots 10°C above the average core temperature after full flux has been applied for 15 minutes. Longer periods for larger cores can be done with Employer's consent.
- C. The average core temperature is not to exceed 10°C above ambient temperature. The core loss should be at least 5 W/kg for a good core. Values ranging from 5-8 W/Kg are acceptable with the core to be verified for any possible mechanical damage. Values from 9-12W/kg can be further substantiated by performing an EL-Cid to assist with decision making.
- D. A report detailing the result of the core flux test, the hot spots repair procedure and the feasibility of the hot spot repairs to be provided to the Employer.
- E. The Employer is to approve the repair prior to the commencement of the work.

4.4.2.4 Other Component Electrical Tests

4.4.2.4.1 Space Heater and Temperature Detector Insulation Resistance Tests

- A. Insulation resistance of space heaters with voltage ratings of 220 volts and winding temperature detectors shall be measured with a 100V megohmmeter.
- B. The minimum acceptable resistance (IR1) is 10 MΩ.

4.4.2.4.2 Bearing Insulation Resistance and Shaft Voltage Tests

- A. The bearing insulation resistance shall be measured on a stationary motor either during assembly or with the motor completely assembled.
- B. On a stationary motor; disconnect the earthing device on the DE bearing and Megger at 500 V_{DC} between the shaft and earthed frame.
 - B.1. Acceptable bearing insulation resistances should exceed one (1) MΩ.
- C. Shaft voltage is checked while the motor is running during a no-load test.
 - C.1. Shaft voltages should not exceed 100 mV for un-insulated ball and roller bearings, and 300 mV for un-insulated sleeve bearings, whichever is applicable.

4.4.2.4.3 Rotor Bar Test

- A. The Elcid and bar to bar test are required by the Employer during motor assessment.
- B. The Induced Current and Loop Test shall only be conducted on the rotor if rotor bar cracks or breaks, as detected by inspections, are thought to be present.
- C. The procedure shall be as follows:

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- C.1. Induce AC currents in the rotor squirrel-cage winding by applying a low voltage across the ends of the rotor shaft, or by a core loop test similar to that of the stator.
 - C.2. Place iron filings or magnetic paper over the rotor and a clear representation of the bar should be seen. If any discontinuity in the bar or misalignment of two sections of bar appears, this indicates a broken bar.
 - C.3. If there is evidence of broken bars, warm the rotor by increasing the applied voltage. This should produce hot spots at the location of a cracked rotor bar, which should be detected and recorded with an infrared scanning device.
 - C.4. During the second part of this test, checks are required for lamination vibrations, which are indicative of a loose core.
 - C.5. There shall be no rotor lamination vibration or hot spots in the rotor bars or end rings.
 - C.6. When a slip-ring motor rotor winding has been repaired and the complete machine is available in the Repairer's works, the rotor open circuit voltage is to be measured and recorded at standstill with the rated voltage applied to the stator.
- D. New methods of Rotor bar and Elcid testing shall be used after approval from Employer.

4.4.3 Mechanical Checks before Assembly

The following mechanical checks and tests shall be performed while the motor is disassembled.

4.4.3.1 Rotor Balancing

- A. All motors being refurbished or repaired shall have the rotor balance checked. In the event of rotor repairs or rewinds, the rotor shall be statically balanced followed by dynamical balancing at rated speed. This is to be performed both before and after any over speed test, where relevant, unless otherwise agreed by the Employer. The rotor shall be balanced after all cleaning, testing, inspections and repairs have been completed. This shall be done in a balancing machine to Dynamic balancing standard ISO 1940/1
 - A.1. G1.0 Balance Quality Grade for motors with 4 or more poles.
 - A.2. G0.4 Balance Quality Grade for 2 pole motors
- B. The following balance weight requirements shall be adhered to for rotor balancing:
 - B.1. Either the motor coupling half or a half key shall be installed on the shaft extension for rotor balancing.
 - B.2. Shaft-mounted cooling fans shall be installed for balancing.
 - B.3. Putty balance weights shall not be used and any putty weights shall be removed.
 - B.4. All balance weights shall be mechanically attached.
 - B.5. Attachment of balance weights to fan blades shall be avoided wherever possible.

4.4.3.2 Rotor and Shaft Run-out

- A. The shaft extensions, bearing journals, and rotor body straightness shall have their total run-out measured with the rotor mounted in a lathe, V-blocks or rollers.

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B. The acceptance criteria for such run-out measurements are as follows:

- B.1. Shaft extension and bearing journal run-out values shall not exceed 0.025 mm for 2 and 4 pole motors.
- B.2. The bearing journal run-out values shall also not exceed 0.025 mm.
- B.3. Rotor core outer diameter run outs as measured at both ends and centre shall not exceed 0.127 mm.
- B.4. The maximum run-out on thrust faces of vertical motors, which is measured with the thrust runner mounted on the rotor, shall not exceed 0.025 mm.

4.4.4 Motor Assembly

4.4.4.1 Mechanical Checks during Assembly

4.4.4.1.1 Concentricity

- A. Concentricity checks in relation to the stator bore shall be conducted for bearing bracket mounting flanges, bearing brackets and bearing housing bores. This shall be done on all 2-pole motors and, where specified, other motors.

4.4.4.1.2 Ball and Roller Bearings

The following checks and measurements shall be made and the results recorded for ball and roller bearings;

- A. The fit between each bearing inner ring and the shaft, or between the inner ring and the mounting hub, and between the bearing outer ring and the bearing housing.
- B. There is an axial space between the ball bearing outer ring and the end cap of the bearing housing to allow for shaft growth. During motor re-assembly, this space shall be measured to ensure that it is adequately sized to prevent contact between the bearing and the end cap as a result of shaft growth under load conditions.
- C. The radial play and axial play acceptance criteria shall be the motor or bearing OEM's design limit.
- D. These bearings shall be installed as specified in subsection 4.2.1.4.1 Anti-friction Bearings inspection.
- E. The type and amount of lubrication grease filled in the bearings.

4.4.4.1.3 Sleeve Bearings

For sleeve bearings, check and record the following during re-assembly;

- A. Bearing bore concentricity by performing three sets of measurements at both ends and in the middle of the bearing. At each location take three readings, 120 degrees apart and at the splits, if applicable. All readings shall all be within 0.025mm of each other and the motor manufacturer's bore tolerances, if available.
- B. The oil ring roundness, measured on three locations that are 120 degrees apart, shall be within 0.127mm of each other.
- C. The fits between each bearing outer diameter and housing must be within the following limits;

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- C.1. For thick shell bearings, unless otherwise specified by the motor manufacturer, such fits should be size-for-size to 0.0254 – 0.0508 mm tight.
- C.2. For thin shell bearings such fits should be size-for-size to 0.0508 mm loose.
- D. Bearing bore to shaft bearing journal clearances by using the bore roundness measurements. The acceptance criteria shall be the motor OEM's design limits. If the motor manufacturer's design limits are unavailable, the maximum diametrical bearing shaft journal to bearing clearance shall be in accordance with Table 5.

Table 5: Sleeve Bearing Clearance Acceptance Criteria

Bearing Journal Diameter [mm]	Minimum Diametral Clearance [mm]	Normal Tolerance Above Minimum Diametral Clearance [mm]
25-to-75	0.101	0.0254
75-to-180	0.002/mm of shaft diameter	0.0508
180-to-250		0.127
250-to-500	0.0005/mm of shaft diameter +0.381	0.127

- E. The contact between the sleeve bearing shaft journal and the sleeve bearing white metal surface, requires verification that there is at least 80% bearing lay in the axial direction, and the lay is on the load carrying portion of the bearing.
- E.1. Bearing scraping shall not be used to meet this acceptance criterion. Re-alignment of the end shields and/or bearings is preferred.
- F. The shaft to bearing housing seal clearance values by measuring seal bores and using measured shaft diameters. The acceptance criterion, if no manufacturer's values are available, shall be 0.05 to 0.1 mm greater than the bearing diametrical clearance.

4.4.4.2 Mechanical Tests and Checks after Assembly

- A. Where possible, the air gap between the stator and rotor shall be checked with feeler gauges at 4 positions 90° apart. The air gap measurement is to be taken at both the drive end (DE) and the non-drive end (NDE). The air gap measurements shall be within $\pm 10\%$ of the average for motors with 4 or more poles and $\pm 8\%$ for 2-pole motors. Corrective action taken to restore the air gap to within this limit shall be discussed with the Employer.
- B. Motors with sleeve bearings, the end-float and magnetic centre shall be checked.
- B.1. The total axial end float of the horizontal motor rotor in the bearings shall be measured by manually rotating the rotor on lubricated bearings. The following are specific requirements for rotor end float.
- The machine bearings should have the minimum end-float not less than the motor manufacturer's design value. If the motor OEM value is unavailable, the minimum end-float shall be in accordance with values in Table 6.
 - If the total end-float is less than the minimum end-float value, modifications shall be made to restore rotor end float to the minimum value.

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Table 6: Sleeve Bearing End-float Acceptance Criteria

Motor Rating [kW]	Number of Poles	Minimum End Float [mm]
Below 200	2	6
200-to-375	2	10
375 and below	4 and above	6
Above 375	All speeds	10

- B.2. Shaft end float limits and magnetic centre shall be marked with indelible lines on the shaft extension or tilting pad guide bearing. Labelling, either on the motor DE bearing or end-shield, the machine rotor end float and magnetic centre in millimetres.
- B.3. The running motor magnetic centre shall not shift from either side of the geometric centre by more than 20% of the total end-float.
- B.4. The magnetic centre line should be provided with a sharp marker from the bearing end cap or dust seal cover, and dimensions of the centre line to the bearing endcap or dust seal cover shall be recorded and marked on the motor.

4.4.5 Routine Test

4.4.5.1 Pre-run electrical checks and tests

- A. The following electrical tests/measurements shall be performed on the motor after assembling and prior to the no-load test-run to be witnessed by the Employer. These tests shall also be witnessed by the Employer and recorded on the pre-run test data section of the Routine Test Certificate.
- A.1. Stator Winding Resistance and percentage imbalance;
- A.2. Stator Winding IR, DAR, and PI,
- If the measured and corrected IR₁ and calculated PI are less than specified critical limit values, the windings must be dried prior to motor testing. If the measured values are within 120% of critical acceptance criteria, the motor may be energised for test-running and the insulation resistance tests subsequently checked at the completion of the test-run.
 - Unless otherwise specified in the Contract, the acceptance criteria for the motor to be delivered, regardless of other test results, is that IR₁ and PI test results must exceed minimum acceptable values as in Table 2.;
- A.3. Space Heater and winding ETD IR tests and functional checks;
- A.4. Bearing RTD/Thermocouple Functional Checks;
- A.5. Bearing insulation IR (if applicable);
- A.6. Rotational direction with supply phases L1, L2, and L3 connected to U1, V1, and W1. When viewed from DE, the direction of rotation shall be clockwise.
- A.7. Locked rotor.

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4.4.5.2 Test Power Supply and Instrumentation Quality

- A. Due to the effect of power supply quality on the electrical machine performance, it is essential that a suitable source of power and careful measurement with accurate instrumentation are employed for correct data and performance to be obtained. The test facility shall therefore have the power supply source and instrumentation that is capable of meeting the following requirements throughout the test duration;
- A.1. The harmonic distortion coefficient, THD, shall not exceed 0.05.
- A.2. The voltage unbalance shall not exceed 0.5%.
- A.3. The frequency shall be within $\pm 0.5\%$ for routine test, and $\pm 0.1\%$ for performance test of motor rated frequency. The power supply frequency range is, therefore, limited to 49.75-to-50.25 Hz for routine tests, and 49.95-to-50.05 Hz for performance test.
- A.4. Variations in frequency during a test shall not exceed 0.33% of the average frequency.
- B. Power supply quality shall be monitored and automatically controlled throughout the test duration. The supply conditions shall be recorded throughout the tests, and such records must form part of the motor test record.
- C. The accuracy of instrumentation used to measure test data shall be in accordance with SANS IEC 60034-2-1 requirements.
- D. The capabilities of vibration measurement instruments shall include the following;
- D.1. Can measure displacement, velocity, acceleration, and phase that require at least two channels.
- D.2. The software must be able to convert the vibration time waveform between acceleration and velocity.
- D.3. Minimum zoom factor of 10 to enable high-resolution spectral analysis. The analyser shall therefore be able to permit time period (maximum frequency) settings of 12 000 CPM (200 Hz) for 1 600 lines of resolution by machine speed.
- D.4. Log amplitude scale.
- D.5. Wide frequency response range of 0 Hz – 20 kHz, as a minimum, for standard vibration measurements. To reliably detect all calculable rolling element bearing defect frequencies, high-frequency vibration analysis instruments that have a frequency response range of 25 kHz – 36 kHz are required.
- D.6. Plots that can be produced include;
- Time waveforms
 - Plots of overall vibration amplitudes
 - Vibration amplitudes in specific frequency bands
 - Trend plots
 - Bode plots.
 - Vibration spectrum and overall vibration in one measurement

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D.7. Recording of run test data shall be computerised and automatically transferred from the measuring instrument to the test report, without human interference.

4.4.5.3 No-load Run

- A. All motors shall be run uncoupled with either the half-key or coupling fitted at rated frequency and voltage in accordance with SANS IEC 60034-2-1 to determine constant losses and other performance parameters.
- B. The routine test run shall be conducted with the motor completely assembled.
- C. Bearings shall be lubricated and cooled as they are designed to be in service, i.e. flood lubrication systems.
- D. Snapshot measurements that are to be recorded every 15-minutes, with the first set as soon as the motor testing power supply requirements are met, are;
 - D.1. Input power,
 - D.2. Line voltages,
 - D.3. Line currents,
 - D.4. Shaft speed,
 - D.5. Supply frequency,
 - D.6. Bearing temperatures and bearing coolant inlet and outlet temperature, and
 - D.7. Winding temperature from the highest reading ETD, and winding coolant inlet and outlet temperatures.
- E. The test run shall be long enough to allow the motor to reach stability, which is when bearing temperatures and no-load losses have reached equilibrium. Motor stability shall therefore be considered reached when, at two successive 30-minute intervals;
 - E.1. The no-load power input at the same voltage varies by not more than 3%, and
 - E.2. The change in bearing temperatures (ΔT), taking coolant temperature changes into account, is within 1°C.
- F. Cold and hot motor horizontal, vertical, and axial vibration measurements shall be taken on both bearing housings.
 - F.1. For time waveform analysis, standard resolution measurements shall be taken on all directions with the vibration analyser set to 1600 lines of resolution and maximum frequency to at most 30 kCPM (500 Hz). The direction that exhibits the highest standard resolution vibration on either end shall have high resolution measurements taken with the analyser set to no less than 3200 lines of resolution and maximum frequency to at most 12 kCPM (200 Hz).
 - F.2. Cold vibration levels shall be taken within five minutes of the motor being started. Other vibration measurements must be taken at 30-minute intervals until thermal stability has been reached.
 - F.3. Hot vibrations measurements shall be conducted when stability has been attained.

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- G. Acceptance criteria for bearing vibrations with the motor solidly bolted to the floor are as per Table 7.

Table 7: Bearing Vibration Acceptance Criteria

Overall vibration levels shall not exceed	No. of Poles
2 mm/s	2-pole motors
1.6 mm/s	4-pole motors
1.2 mm/s	6-pole motors
1.0 mm/s	8-pole motors
0.8 mm/s	10-pole motors
0.5 mm/s	18-pole motors

- H. The change between cold and hot vibrations shall not exceed 20%.
- I. Vibration spectra for rolling element bearings shall not show any calculable bearing defect frequencies.
- J. The acceptance criteria for bearing temperature rise when the motor has reached stability are;

J.1. For Ball and Roller Bearings;

- 35°C on motors with 4 or more poles
- 40°C for 2 pole motors.

J.2. For Sleeve and Tilting Pad Bearings;

- 45°C for vertical motors when measured by the ETD on thrust pads,
- 30°C for on motors with shaft diameter less than 70 mm,
- 40°C for 2 and 4-pole motors with shaft diameter between 70 and 100 mm,
- 30°C for 6-pole and slower motors with shaft diameter between 70 and 100 mm,
- 45°C for 2 and 4-pole motors with shaft diameter above 100 mm,
- 35°C for 6-pole and slower motors with shaft diameter above 100 mm,

- K. Other measurements and checks that shall be conducted and recorded during the rated frequency and voltage test run are;

K.1. Shaft Voltage,

K.2. Bearing oil and grease leaks,

- L. Mechanical Tests and Checks After Assembly (Sub-section 4.4.4.2) No-load loss separation test shall be conducted after all required measurements at rated voltage and stability have been recorded. Recording of winding temperature, average line voltage and current, and power input at rated frequency and at voltages ranging from 120% of rated voltage down to the point where further voltage reduction increases the current.

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- M. To end the test-run, the following measurements shall be conducted during the motor rundown when it has been de-energised;
 - M.1. The run-down time for 2-pole motors shall be recorded and abnormal values resolved to the Employer's approval.
 - M.2. The total end-float for horizontal motors with sleeve bearings.
- N. Electrical tests that are to be conducted on a hot motor after the test run are;
 - N.1. Stator winding Insulation Resistance, Dielectric Absorption (DA), Polarization Index (PI) before and after the following test,
 - N.2. Stator AC or DC Hi-pot.
 - N.3. DC Step Voltage Test (if requested)
- O. On completion of the bearing run, the sleeve bearings shall be opened up for inspection to verify that there is at least 80% contact between the journal and the white metal surface in the axial direction in the loading area of the bearing. Bearing scraping shall not be used to meet this criterion.

4.4.6 Performance Test

Performance tests shall be conducted to refurbished/repaired motors that has been rewound i.e. stator rewound or rotor rewound/rebar.

- A. The motor shall be loaded, as per preferred loading method, to 25%, 50%, 75%, 100%, 115% and 130% of rated capacity to determine the efficiency at each load point. The loading shall be in descending order, i.e. from highest to lowest load points.
- B. The motor efficiencies shall be determined with the machine at the specified temperature.
- C. The temperature rise test shall be conducted on a motor loaded to 100% of its rated capacity.
- D. Type tests shall consist of the following measurements/calculations:
 - D.1. Stator winding temperatures;
 - D.2. Rated load slip;
 - D.3. Rated load stator winding and bearing temperature rises;
 - D.4. Three-phase locked rotor current and torque;
 - D.5. Speed/torque and speed/current characteristics; and
 - D.6. Vibration at full load if possible.
- E. The permissible temperature rise for all motors shall be in accordance with limits specified in the Thermal Class section. The final temperature and the slip or speed at the reduced voltage shall be recorded. Where it is not possible to load a motor fully in the works, the Employer may accept the "mixed frequency" method of temperature rise testing provided the manufacturer can justify the results obtained by this method. A partial load test may also be used subject to the same stipulation. If approved, the temperature rise test may be done on site.
- F. The stator winding temperature used to calculate the rated load temperature rise shall be determined from both the rated test resistance method (the Resistance Method), and the directly measuring

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ETDs (the ETD Method). Both methods shall yield temperature rise within acceptable limits for the specified Thermal Class for motor acceptance.

- G. If modifications have been performed to a terminal box, it is required that the terminal box has been type tested according to the relevant regulations and standards and is accompanied with a type test certificate.

4.4.6.1 Thermal Class (Temperature Limits)

- A. Stator windings shall be insulated with a Class F (155°C) or higher insulation system that has been proven by usage or tests as per applicable parts of SANS IEC 60034-18.
- B. The winding temperature rise (T) at rated output shall not exceed 80°C (Class B Insulation System), as measured using the resistance method, subject to the following:
- B.1. The reference coolant temperature on which to base the design is either 40°C or more. The reference coolant temperature shall not be less than 40°C.
- B.2. The design reference coolant for machines with primary and secondary coolants shall be the secondary coolant, with temperatures as stated above.
- C. Both the resistance and ETD methods shall be used to determine winding temperatures as per SANS IEC 60034-1. If the resistance method cannot be conducted by the Repairer, the ETD method may be approved for use as the only method provided that the ETD location can be proven, through the Employer witnessed infrared thermographs during the test, to be at the hottest part/s of stator components.
- D. The Employer reserves the right to reject a motor where any of the two methods show a rise above the contracted winding temperature rise.
- E. The temperature differential between same components that are in the same position shall not exceed 2°C. The temperature differential between all stator components shall not exceed 5°C. The Employer reserves the right to reject a motor with thermal scans that show temperature differentials above the stated limits.
- F. Test facilities shall be equipped with calibrated infrared thermal imaging camera/s. The Repairer shall conduct thermal image scans of all visible running motor components, including open (removed heat exchanger) stator windings and core, during routine and performance testing. These thermal images shall form part of the motor test reports.

5. RECORDS

- A. Each Motor repair shall generate the following records.
- B. Records to be kept by the Employer for the life of the Station shall include;
- B.1. Motor Breakdown Report. An example is provided in APPENDIX C,
- B.2. Protection Operating Report
- B.3. Assessment Sheet/Report and failure report received from the Repairer,
- B.4. The final repair Scope of Work, including cost thereof,
- B.5. All tests and check reports received from the Repairer.

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- B.6. Repair vs Replacement Analysis and recommendations, where applicable.
- B.7. A copy of Quality records,
- C. The Repairer shall keep the following records, which shall be submitted to the Employer upon completion of the assessment and/or repair contract, for a minimum of five years.
 - C.1. Motor Breakdown Report, received from the Employer,
 - C.2. Assessment Sheet/Report,
 - C.3. Failure Report,
 - C.4. Repair scope of work,
 - C.5. Quality records,
 - C.6. All tests and check reports.

6. AUTHORISATION

This document has been seen and accepted by

Name & Surname	Designation
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Bernie Jansen	Camden Power Station – Motor Engineer
Virginia Nama Mbe	Duvha Power Station – Motor Engineer
Kgotso Makweya	Grootvlei Power Station – Motor Engineer
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7. REVISIONS

Date	Rev	Compiler	Remarks
Dec 2013	0.1	P. Ruthenberg	Standard converted to Work Instruction
Jun 2014	0.2	L. Mntambo	Informal Review by Motor Care Group
Sep 2014	0.3	L. Mntambo	Informal Review by Rotating Electrical Machinery Study Committee
Jan 2015	0.4	L. Mntambo	Document for Comments Review
Jan 2015	0.5	L. Mntambo	Draft Document for Comments Review
Feb 2015	1	L. Mntambo	Final Document for Authorisation and Publication
Aug 2017	1.1	M. Manyage	Removal of GGS reference, correction of document reference number and signatory page. No Technical Content Changes
Sep 2017	2	M. Manyage	Final Rev 2 Document for Authorisation and Publication
Jan 2024	2.1	M. Manyage	First Draft for Comments Review Process
Feb 2024	2.2	M. Manyage	Second Draft for Comments Review Process
Nov 2025	2.3	M. Manyage	Final Draft after Comments Review Process
Nov 2025	3	M. Manyage	Final Rev 3 Document for Authorisation and Publication

8. DEVELOPMENT TEAM

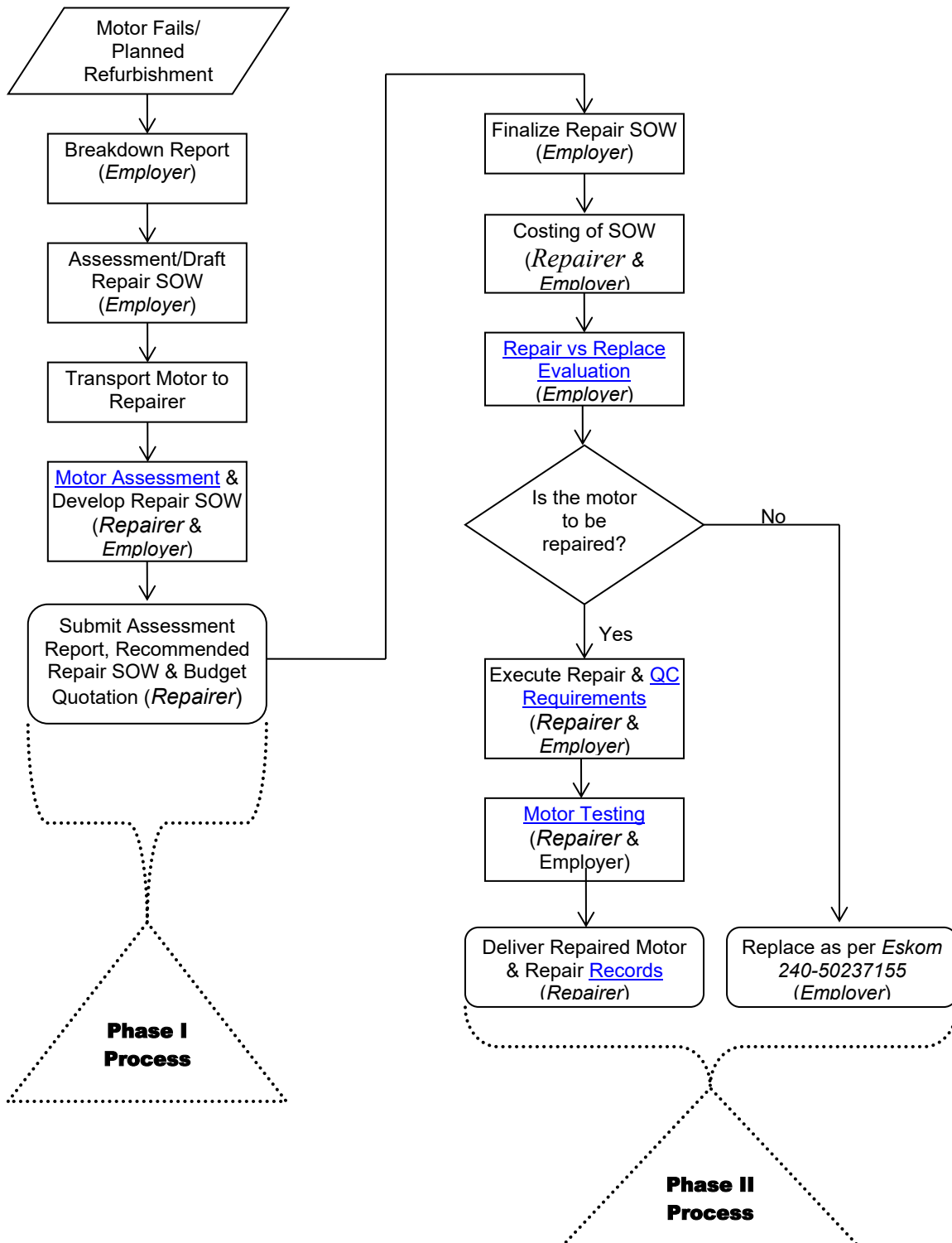
The following people participated in the development of this document.

- P Ruthenberg
- Linda Mntambo
- Marubini Manyage

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APPENDIX A: MOTOR REPAIR FLOWCHART



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APPENDIX B: ELECTRIC MOTOR REPAIR AND REFURBISHMENT ASSESSMENT FORM

The assessment Form can be found in ESKOM Document [240-87739380](#)

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APPENDIX C: MOTOR BREAKDOWN FORM

The Motor Breakdown Form can be found in ESKOM Document 559-69067162

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APPENDIX D: TEST EQUIPMENT SPECIFICATIONS

TEST	TEST EQUIPMENT REQUIREMENTS
Tan-δ Test	An appropriate size 50 Hz AC test unit to provide the required measurements at applied voltage from 20% to 100%, at 20% increments of motor rated line-to-line voltage shall be used. The accuracy of the bridge shall be, at worst, 1%.
Stator Coil Tests	The impulse generator used shall be capable of generating impulses with peak values in excess of 50 kV and front rise times of 0.1 to 0.2 μ s. The test voltage and wave shape of the impulse wave shall be subject to the <i>Employer's</i> approval.
Winding Insulation Resistance Tests	Insulation Resistance (IR) tests shall be conducted with a capable megohm meter to determine equipment which will on output provide a plotted trend of the measured insulation resistance as a function of time throughout the entire duration of the measurement of the IR_{1min} and IR_{10min} . The plot must be from readings measured every 5-seconds. From the trend the Dielectric Absorption Ratio (DAR) and Polarization Index (PI) will be calculated by measuring and recording the 30-second reading (IR_{30sec}), 1-minute reading (IR_{1min}), and 10-minute reading (IR_{10min}). The DC megohm meter shall be capable of developing and displaying test voltages.
Stator Winding Resistance Test	A bridge-type instrument or digital ohmmeter capable of measuring and displaying milliohms shall be used to record the three-line terminal-to-terminal stator winding DC resistance values, i.e., R_{UV} , R_{VW} and R_{WU} . Letters U-V-W may be substituted by A-B-C, depending on the terminal notation.
No-load Test	As per section 4.4.5.3 and as per <i>Eskom 240-50237155</i> .

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Test Power Supply and Instrumentation Quality	The test facility shall have the power supply source and instrumentation that is capable of meeting the following requirements throughout the test duration; - The harmonic distortion coefficient, THD, shall not exceed 0.05. - The voltage unbalance shall not exceed 0.5%. - The frequency shall be within $\pm 0.5\%$ for routine test, and $\pm 0.1\%$ for performance test of motor rated frequency. The power supply frequency range is, therefore, limited to 49.75-to-50.25 Hz for routine test, and 49.95-to-50.05 Hz for performance test. - Variations in frequency during a test shall not exceed 0.33% of the average frequency. - Power supply quality shall be monitored and automatically controlled throughout the test duration. The supply conditions shall be recorded throughout the tests, and such records must form part of the motor test record. - The accuracy of instrumentation used to measure test data shall be in accordance with SANS IEC 60034-2-1 requirements. - The capabilities of vibration measurement instruments shall include the following; - Can measure displacement, velocity, acceleration, and phase. - The software must be able to convert the vibration time waveform between acceleration and velocity. - Minimum zoom factor of 10 to enable high-resolution spectral analysis. The analyser shall therefore be able to permit time period (maximum frequency) settings of 12 000 CPM (200 Hz) for 1 600 lines of resolution by machine speed. - Log amplitude scale. - Wide frequency response range of 0 Hz – 20 kHz, as a minimum, for standard vibration measurements. To reliably detect all calculable rolling element bearing defect frequencies, high-frequency vibration analysis instruments that have a frequency response range of 25 kHz – 36 kHz are required. - Plots that can be produced include; - Time waveforms - Plots of overall vibration amplitudes - Vibration amplitudes in specific frequency bands - Trend plots - Bode plots. - Vibration spectrum and overall vibration in one measurement - Recording of run test data shall be computerised and automatically transferred from the measuring instrument onto the test report, without human interference.
Crane	The lifting Cranes shall be suitably rated, with excess lifting capacity for the size of motor to be lifted.
Vibration Measurements	For time waveform analysis, standard resolution measurements shall be taken on all directions with the vibration analyser set to 1600 lines of resolution and maximum frequency to at most 30 kCPM (500 Hz). The direction that exhibits the highest standard resolution vibration on either end shall have high resolution measurements taken with the analyser set to no less than 3200 lines of resolution and maximum frequency to at most 12 kCPM (200 Hz).

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AC Hi Potential Test	Equipment which is capable of an output AC voltage of three times the rated Line-Line voltage of the motor under test. The high-voltage test procedure shall comply with IEC Standard 60034-1.
DC Hi Potential Test	The AC supply circuit utilising the stable system 50Hz source should be free from intermittent loads and transients. A test set with 0.1%-line regulation or better high voltage output is required. The output current meter must be capable of selecting several current ranges for improved sensitivity to typically measured microamperes. Current measurements must be either voltage or time based. If the test set includes overcurrent trip, it should be calibrated for a setting high enough to avoid insulation-stressing inadvertent trips during the test.
Impulse Testing	As per Eskom Standard 240-50237155 all coils installed in the stator shall have inter-turn insulation surge/impulse tested in accordance with IEEE Std 522, while tests conducted on sample coils shall be conducted in accordance with SANS IEC 60034-15.
Performance Test	As per section 4.4.6 and as per <i>Eskom 240-50237155</i> .

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