

EEMUA Publication 227 Management of ageing electrical assets

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Management of ageing electrical assets

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Contents

Preface.....	VIII
Abbreviations/Acronyms used in this Guide	IX
1 Introduction.....	1
1.1 Purpose	1
1.2 Scope.....	2
2 General management of ageing assets.....	3
2.1 Usual references/resources.....	3
2.2 Benefits of replacement and updating	3
2.3 Other considerations	4
2.4 Obsolescence.....	4
3 Uninterruptable Power Supplies and Battery Systems	5
3.1 Technology introduction	5
3.2 Typical Failure modes.....	6
3.2.1 UPS.....	6
3.2.2 Batteries.....	6
3.3 Condition monitoring techniques.....	7
3.3.1 Temperature measurement.....	7
3.3.2 Battery cell voltage measurement	7
3.3.3 Ripple current measurement.....	8
3.3.4 Connection resistance measurement.....	8
3.3.5 Capacity test.....	8
3.3.6 Battery impedance measurement	8
3.4 Expected/accepted values	8
3.5 Assessing risk of failure	9
3.6 Life extension methods.....	9
3.6.1 UPS.....	9
3.6.2 Batteries.....	9
3.7 Equipment specific useful extras/examples.....	10

4 Electrical drives	11
4.1 Technology introduction	11
4.2 Typical Failure modes.....	11
4.3 Condition monitoring techniques	12
4.4 Expected/accepted values.....	12
4.5 Assessing risk of failure	13
4.6 Life extension methods.....	13
4.7 Equipment specific useful extras/examples.....	13
5 Electrical protection devices	14
5.1 Technology introduction	14
5.2 Typical Failure modes.....	14
5.3 Condition monitoring techniques.....	15
5.4 Expected/accepted values.....	15
5.5 Assessing risk of failure	15
5.6 Life extension methods.....	15
6 Power cables.....	17
6.1 Technology introduction	17
6.2 Typical Failure modes.....	17
6.2.1 Cabling environment	17
6.2.2 Cable UV degradation.....	18
6.2.3 Degradations associated with cable trays	18
6.2.4 Moisture ingress	18
6.2.5 Placticizer migration.....	19
6.2.6 Oxygen degradation.....	19
6.2.7 Water Treeing.....	19
6.2.8 Electrical treeing.....	19
6.3 Condition monitoring techniques	19
6.4 Expected/accepted values.....	20
6.5 Assessing risk of failure	20
6.6 Life extension methods.....	20

7 Switchgear (HV and LV)	21
7.1 Technology introduction	21
7.2 Typical Failure modes.....	21
7.3 Condition monitoring techniques.....	21
7.4 Expected/accepted values	22
7.5 Assessing risk of failure	22
7.6 Life extension methods.....	22
7.7 Equipment specific useful extras	22
8 Transformers	23
8.1 Technology introduction	23
8.2 Typical Failure modes.....	23
8.3 Condition monitoring techniques.....	24
8.3.1 On Line Testing.....	24
8.3.2 Other On-Line Tests.....	25
8.3.3 Off-line tests.....	25
8.4 Expected/accepted values	26
8.5 Assessing risk of failure	26
8.6 Life extension methods.....	27
8.7 Equipment specific useful extras/examples.....	28
9 Generators and motors.....	29
9.1 Technology introduction	29
9.2 Typical Failure modes.....	29
9.3 Condition monitoring techniques.....	30
9.3.1 Stator Winding Off-Line Tests.....	31
9.3.2 Stator Winding Insulation Resistance and Polarisation Index	31
9.3.3 Loss Angle and Winding Capacitance	31
9.3.4 Partial Discharge Testing from Machine Terminals	32
9.3.5 Partial Discharge Location Detection.....	32
9.3.6 Winding DC Resistance	32
9.3.7 Winding AC Impedance.....	32
9.3.8 Generator Stator Core Tests.....	33
9.3.9 Remote robotic inspection	35

9.4 Expected/accepted values	35
9.5 Assessing risk of failure	35
9.6 Life extension methods.....	36
Appendix A Example inspection templates.....	37
Appendix B Equipment Assessment Process.....	56
Appendix C Examples of ageing-related failures	62
References	63
Bibliography.....	65
EEMUA Publication: Feedback Form	66

Tables

Table 1:	Vented lead acid (VLA) battery – common causes of failure	6
Table 2:	Valve regulated lead acid (VRLA) battery – common causes of failure.....	6
Table 3:	Nickel cadmium battery – common causes of failure	6
Table 4:	Battery degradation.....	7
Table 5:	Battery design life by type	9
Table 6:	Frequency of UPS maintenance.....	9
Table 7:	Frequency of battery maintenance.....	10
Table 8:	Transformer life expectation	26

Preface

The idea of 'Asset Management' has been around for a long time. EEMUA itself was originally founded in 1949 with the tagline "Leadership in industrial asset management" and has been instrumental in promoting good practice ever since. More recently however, it has developed into an engineering discipline in its own right, with increasing emphasis on the systems used by organisations to manage their assets over their full lifecycle.

To that end, plenty of guidance has been written that outlines general good practice, and some (including the Health and Safety Executive Research Report 823 Plant Ageing Study) has been published that specifically focuses on the management of ageing assets. Over time however, the members of EEMUA's Electrical Engineering Committee (ELC) found themselves discussing issues related to ageing electrical assets more and more frequently. With increasing UK regulator focus on the topic, it was clear that guidance more tailored to specific equipment types was required, not only to help improve standards across industry but also to help agree on accepted good practice.

This publication does not therefore aim to cover old ground but rather focus on equipment specific details such as failure rates, maintenance regimes and life extension techniques.

I hope you find this guidance useful and if you would like to contribute to future editions as we plan to expand the number of equipment types covered, please do get in touch.

Huw Jones
Chairman, EEMUA Electrical Committee

Abbreviations/Acronyms used in this guide

ACB	Automatic Circuit Breaker
AGSC	Air Gap Search Coil
ANSI	American National Standards Institution
AVR	Automatic Voltage Regulator
DER	Distributed Energy Resource
DGA	Dissolved Gas Analysis
ELCID	Electromagnetic Core Imperfection Detector
EPDM	Ethylene Propylene DiMonomer
EPR	Ethylene Propylene Rubber
EU	European Union
HFCT	High Frequency ferrite Current Transformer
HMI	Human Machine Interface
HSE	Health and Safety Executive (UK)
HV	High Voltage
IEC	International Electrotechnical Commission
IDMT	Inverse Definite Minimum Time
IGBT	Insulated Gate Bipolar Transistor
IR	Insulation resistance
ISO	International Standards Organization
IT	Information Technology
LV	Low Voltage
MV	Medium Voltage
NiCad	Nickel-Cadmium
PCB	Polychlorinated Biphenol
PD	Partial discharge
PE	Polyethylene
PI	Polarization Index
PVC	Polyvinylchloride

RAM	Random Access Memory
RSO	Recurrent Surge Oscillograph
TDR	Time Domain Reflectometry
TEV	Transient Earth Voltage
TVA	Tennessee Valley Authority (probe)
UPS	Uninterruptable Power Supply
UV	Ultra Violet
VLA	Vented Lead Acid
VRLA	Valve Regulated Lead Acid
VSD	Variable Speed Drive
XLPE	Cross-linked Polyethylene

1 Introduction

Electrical equipment is often designed with a relatively long lifetime (typically 20 years) and the electrical engineer responsible for it has the challenge of ensuring the equipment's integrity over this period, if not well beyond it. In justifying the continued service of equipment, the engineer has to take commercial (reliability, availability, replacement costs) and safety considerations into account.

This is a difficult task, and in addition to general good asset management practice, the electrical engineer requires specific guidance relating to:

- Identifying potential failure mechanisms on ageing electrical assets;
- Methods of detecting early signs of failure mechanisms;
- Ways of calculating remaining expected life of electrical assets;
- Maintenance methods to extend electrical asset life; and
- Demonstrating the benefits of replacing equipment before failures occur.

Complicating the process further, the engineer overseeing the design and installation is less likely than ever before to be the same engineer overseeing its decommissioning. Knowledge transfer systems are outside the scope of this document but the need to keep useful records and specifically any assumptions made, should be remembered, especially when justifying life extension.

1.1 Purpose

EEMUA Publication 227 aims to provide a coherent, proactive system for managing certain ageing electrical assets. Collating users' existing knowledge in an anonymous manner will help overcome the difficulties often faced in accessing or determining equipment failure rates.

The caveat however, is that there is no guarantee that contributing users will have experienced all of the environmental or manufactured possibilities which could significantly impact upon the validity of any conclusions drawn.

At the very least, this publication will provide useful reference points for others to measure their performance against and will hopefully be a useful tool in defending good practice to the regulator.

The hope is that this guidance, by helping engineers to better predict "end of life", will also help reduce the number of catastrophic failures, enable engineers to take a more proactive approach and generally improve awareness within industry of the breadth of issues associated with managing ageing electrical assets.

1.2 Scope

This publication is focused on six types of electrical equipment that the EEMUA Electrical Committee prioritised as those where additional guidance would be most useful, either due to a lack of other guidance or an increase in incidents related to ageing asset issues.

Each chapter (equipment type) is purposely formatted in a similar way to better enable the reader to navigate this publication, with the expectation that it will be repeatedly referred to over time.

2 General management of ageing assets

A significant part of asset management is decision making. This is a knowledge-based risk management process, in which the knowledge is the business criticality of the asset, its condition and the impact of the trend line of its whole life cost. Causative factors for whole life cost will include the need to schedule more frequent inspections as asset performance ceases to be robust and predictable, more frequent maintenance and diminished availability of spares. There is a trend to view management of existing assets, including the investment in their maintenance, as an integral part of the corporate investment programme rather than an operating cost. In EEMUA's experience this is the result of the perception that overall business costs should reduce year on year and the view that maintenance costs are less than initial purchase costs on a total cost of ownership basis. It is likely that the pressure on costs will continue and so therefore will the practice of running assets beyond their original book life.

A further factor is the need to view business costs as more than just the directly attributable total cost of ownership. There is also the need to consider the cost of disruptive effects which can result from replacement of a single component with a more modern alternative. For example, a modern replacement motor of appropriate characteristics might not fit the footprint of the original, which might necessitate reconfiguration of surrounding plant at considerable additional cost. Factors such as this will tend to drive careful management and refurbishment.

Even in the relatively harsh environment of national power transmission and distribution, some assets (mainly underground cables) are nearly 100 years old. Within a benign environment, other electrical assets are capable of functioning for 40 years or more. Given that this is longer than a typical working life with either the manufacturer or the user company, continuity of expertise may require serious planning, likewise spares policy and record keeping. More modern equipment may contain some electronic components, for which problems are likely to be the obsolescence of custom parts which were never made in large quantities and the provenance of available replacements.

2.1 Useful references/resources

Review of Asset Management Best Practice BBRT-2556-RP0003^[1] from the UK Office of Rail Regulation contains in Appendix B a useful overview of a number of different strategies of use for ageing asset management.

Guidance such as ISO 55000 series outlines good business practices for managing assets.

2.2 Benefits of replacement and updating

There are benefits to updating equipment – for example modern protection relays might operate more quickly than old relays. Similarly modern AVR's will respond more quickly than old AVR's and minimise voltage disturbances affecting other equipment. In some cases the cost of replacement for commodity items such as small transformers may be similar to cost of repair or refurbishment, in which case it would be preferable to replace, as a longer trouble-free life might be expected.

2.3 Other considerations

Other point to consider are:

- Availability of spares of good provenance, and the reliability and dependability of the supply chain;
- Impact of environmental protection legislation, for example limiting use of asbestos, mercury, lead and cadmium;
- Demands to increase energy efficiency, which may result in future legislation;
- Availability of competent persons necessary for maintenance, repair, refurbishment and the manufacture of spares;
- Compliance with updated safety legislation;
- Documentation control and historical record keeping for repairs, maintenance and any change of configuration or use.

Note that equipment that has been generally reliable should be included in any assessment as it may not have had much investment as a result.

2.4 Obsolescence

Not all obsolescent equipment will have attained great age. In some cases obsolescence is driven by technological breakthrough, or radical change in usage requirements. Furthermore, not all old equipment is obsolescent. Relatively static technology and usage patterns may result in the same product being available with only minor changes through several installation life cycles.

3 Uninterruptable Power Supplies and Battery Systems

3.1 Technology introduction

UPSs (including both AC and DC power supplies) and their battery systems are used to supply emergency power to safety critical systems. They are one of the few electrical systems explicitly referenced in the UK HSE Guidance on Managing Ageing Plant, RR823[2].

UPS systems tend to fall into 2 categories, commercial UPSs which are frequently used for IT applications and industrial UPSs which are more normally used in petrochemical and oil and gas applications.

Commercial UPS designs tend to focus on initial capital cost, efficiency and footprint rather than the complete life-cycle costs. The commercial UPS may also have a significantly higher battery voltage to reduce losses, increase efficiency and hence operating costs. They tend to have lower immunity to surges, shorter design life, typically less than 10 years and are more likely to experience obsolescence related problems.

Industrial UPSs are designed for operation in harsher power supply environments in which surges and harmonic supply distortion can be high. Galvanic isolation is normally provided. They are normally designed for 15 to 25 year operation.

The configuration of the UPS and the associated battery systems have a significant impact on the availability of power. They are typically arranged as follows:

- Single UPS for less critical loads that have a single power supply input.
- Dual parallel redundant for more critical loads that have a single power supply input.
- Dual independent UPS for critical loads that have 2 power supply inputs.

Faults on UPS systems can also have an impact on the downstream equipment being powered, e.g. excessive ripple on the DC power supply for nearby switchgear and tripping can have a detrimental impact on the internal power supplies of modern digital protection relays.

Recent developments in battery technology have led to increasing use of lithium- based battery types, some of which are now available in UPSs, however to date these UPSs have been of the commercial type. Particular advantages claimed as compared to VRLA batteries in commercial type UPS are longer life (8 years rather than perhaps 3-5 years), faster recharge time (6-8 hours rather than 24 hours), higher number of charge/discharge cycles (> 1000 as compared to about 500) and much higher energy density in a lower weight package. Further developments for grid applications of lithium batteries may eventually also result in their adoption in industrial UPSs.

3.2 Typical Failure modes

3.2.1 UPS

UPS systems include components with limited life expectancy such as:

- Filter capacitors.
- Cooling fans.
- Internal RAM batteries.
- Power cards and associated control cards

Filter capacitor life is heavily impacted by temperature and current. They fail in short-circuit mode.

In order to ensure equipment operates satisfactorily the limited life components should be changed in line with the manufacturer's recommendations.

Typical replacement periods are 8 to 10 years for capacitors and 4 to 5 years for cooling fans, 10 years for power cards and 15 years for control cards.

In addition, internal components such as microprocessors can have limited spares support life.

3.2.2 Batteries

Tables 1 to 3 show common causes of failure with the most commonly used industrial battery types, i.e. vented lead acid (VLA), valve regulated lead acid (VRLA) and nickel cadmium batteries.

Table 1 Vented lead acid (VLA) battery – common causes of failure

Failure mode	Cause
Grid corrosion	High temperature. Overcharging. Frequent deep cycling. Normal battery ageing.
Internal short circuits	Sediment build up as a result of grid corrosion. Positive grid growth as a result of normal battery ageing.
Plate sulphation	Prolonged undercharging. Prolonged storage in a discharged state.

Table 2 Valve regulated lead acid (VRLA) battery - common causes of failure

Failure mode	Cause
Grid corrosion	High temperature. Overcharging. Frequent deep cycling. Normal battery ageing.
Electrolyte loss (dry out)	Overcharging. High rate charging. Excessive ripple current. High temperature.

Table 3 Nickel cadmium battery – common causes of failure

Failure mode	Cause
Gradual capacity loss	Normal ageing. Long periods of float charging without intermittent discharges.

Table 4 Battery degradation

Variable condition	Impact on life of battery		
	Vented lead acid	VRLA	Nickel Cadmium
High Temperature	Medium impact	Highest impact. VRLA battery life typically reduced by 50% for each 10° C increase above design temperature (Arrhenius effect). Temperature compensation ensures charging is matched to battery.	Lowest impact.
Ripple current Note 1	Medium impact	High impact	Lowest impact.
Deep cycling	Vented lead acid batteries can be adversely affected by the discharge.	Gel VRLA designs have a good tolerance to discharge cycling.	Lowest impact. Batteries with thicker plates are less suited to deep cycling applications.

3.3 Condition monitoring techniques

The following tests can be used as indicators for the condition of the battery system.

3.3.1 Temperature measurement

Temperature measurements can be taken from the negative terminal post with the battery on load or in the case of VLA batteries from the sampling of electrolyte (pilot test).

Thermography can also provide indication of high temperature.

High temperature can be an indication of:

- Elevated float charging voltage and current.
- Excessive ripple current.
- Elevated ambient temperature

An individual cell with high temperature requires further investigation.

3.3.2 Battery cell voltage measurement

Cell voltage measurement can provide an indication of the state of a battery.

Measurement can be continuous individual cell monitoring or by periodic measurement.

Low cell voltage can be an indication of battery/string undercharged or internal cell short.

High cell voltage can be an indication of an overcharged cell leading to accelerated corrosion and electrolyte loss.

Voltage imbalance can indicate that the DC wiring is earthed.

3.3.3 Ripple current measurement

Trending of the ripple current over time can indicate the health of the DC charging circuit and filter. Excessive ripple can be an indication of filter component failure.

An increase in ripple current requires investigation.

3.3.4 Connection resistance measurement

Poor contact between the inter-cell connections can be detected by a high resistance measurement value.

Poor inter-cell contact can also be shown using thermography if the test is carried out with the battery system on load.

High connection resistance can be an indication of poor contact between inter-cell connector and battery post or a damaged connector.

3.3.5 Capacity test

This provides a definite indication of remaining battery capacity.

Poor performance on capacity test can indicate that the battery requires replacement.

3.3.6 Battery impedance measurement

Battery impedance is typically performed using a meter which applies an AC current to the battery and measures the resulting AC voltage.

The resistance is determined by the use of ohms law.

An increasing battery impedance trend can indicate the battery requires replacement.

3.4 Expected / accepted values

It is difficult to provide failure rate statistics for batteries because there is a clear differentiation between manufacturing defects and failures caused by operating conditions.

Battery failures due to operating conditions may include application usage, environmental conditions such as temperature, discharge rates, re-charge regimes, damage caused at time of installation and overall general maintenance.

The design life of the different battery types under ideal conditions is shown in table 5.

Table 5 Battery design life by type

Battery type	Design life
Vented lead acid	20 years +
VRLA (Eurobat)	
• Standard commercial	3 – 5 years
• General-purpose	6 – 9 years
• High-performance	10 – 12 years
• Long life	12 years +
NiCad	20 years +

3.5 Assessing risk of failure

Manufacturer's recommendations for maintenance periods should always be followed.

The capacity test for batteries provides the best indication of the state of the battery system and batteries should be replaced when capacity is reduced to 80% of their rated value.

3.6 Life extension methods

3.6.1 UPS

Table 6 Frequency of UPS maintenance

Monthly	Check: • Voltage, current, frequency parameters. • Fan operation and filters. • Ambient temperature.
Semi annually	Analyse the event log data (if available) and take corrective action. Visual inspection of equipment. Check air filters if provided.
Annually	Functional check of UPS system, e.g. transfer to bypass system and back. In the case of dust contamination clean the system using a vacuum cleaner. Check the charge voltage in case of drift and that it falls within the limits specified for any replacement battery.
Periodic	Functional check of UPS system, e.g. transfer to bypass system and back. In the case of dust contamination clean the system using a vacuum cleaner.

3.6.2 Batteries

- Ensure temperature compensation of applied charging voltage to batteries.
- Ensure ripple current is within manufacturers recommendations to avoid the heating effect caused by the battery internal resistance.

Guidance on permissible ripple currents for lead acid and nickel cadmium batteries based on battery capacity is provided in IEC 62485 – 2[3].

- iii. Ensure depth of and frequency of cycling of battery systems is within the manufacturer's recommendations.

Table 7 Frequency of battery maintenance

Recommended standard	IEEE 450[4]	IEEE 1188[5]	IEEE 1106[6]
Battery type	Vented lead acid	VRLA	Nickel cadmium
Test			
Visual inspection	Monthly	Monthly	Quarterly
Ambient	Monthly	Monthly	
Ripple voltage/current	Monthly	Monthly	
Pilot cell readings	Monthly		Quarterly
Float voltage – battery	Monthly	Monthly	Quarterly
Float voltage – each cell	Quarterly		Semi annually
Specific gravity	Pilot cell – monthly	Not required	Not required
Temperature	Pilot cell – monthly	Pilot cell – monthly	Pilot cell – monthly
Connection torque	Annually		Once after installation
Connection resistance			Not required
Internal impedance or conductance			Not required
Battery capacity	At intervals not exceeding 25% of expected service life thereafter. Annually when battery shows signs of degradation or has reached 85% of service life.		5 yearly intervals thereafter. Annually when battery shows signs of excessive capacity loss.

3.7 Equipment specific useful extras/examples

Maintaining UPSs and battery systems under a maintenance contract helps ensure that equipment meets the expected availability requirements of the safety critical systems. Specifying industrial type UPSs from manufacturers that will guarantee a 20+ year support helps to ensure that obsolescence will be less of a problem. The contractual agreement with the supplier should ensure that obsolete components are provided with a backwards compatible solution in the future.

4 Electrical drives

4.1 Technology introduction

Variable Speed Drives cover a wide variety of systems and sizes. For this document, Variable Speed Drives (VSD) are for larger scale motors used in various applications including fan drives, compressor drives and ship propulsion units.

The VSD has the following basic components:-

Supply breaker:	This provides the electrical supply to the circuit breaker.
Transformer:	The conventional voltage range for the VSD is higher than the required voltage within the VSD. Therefore a transformer is generally used to step down the voltage for the drive. Thus, the conventional supply may be 11 kV but the VSD may only use 3.4 kV. Transformers may also be used for phase shifting to reduce harmonic generation and certain applications may use them to step up the drive output voltage to the motor.
Electronic Module:	This module contains the electronics that convert the AC supply to DC to allow for control and modulation, before the power signal is then converted back to AC.
Apparatus:	The apparatus is the driven item(s) such as a motor or compressor.
Cabling:	There is a need for cabling between the various components. Great care is needed on the design of the cabling and the location of the apparatus as harmonics and distortion can significantly affect the operation of the Electronics Module. There are generally detailed cable lengths and types that are specified by the manufacturer.

Other components often include:

- harmonic filters;
- reactors; and
- cooling systems (air or water)

4.2 Typical Failure modes

The VSD can fail because of any single component failure described above, and potentially also because of component failures within the electronic module.

Each of the individual components (switchgear, transformer, cable and apparatus) have failure modes described in the individual sections within this document. The electronic module can have the following failures:-

Thyristor failure:	While rare, the thyristor module (or IGBT devices) can fail catastrophically leading to the drive failing to operate correctly.
Software fault:	The VSD generally has a software protocol that controls the various aspects of the control of the DC system. This software can be corrupted or “freeze” if the change management is not correct.
Card Failure:	There are generally electronic cards located within the panel. Any part of the system that uses electrolytic capacitors will be subject to component failure. This may affect filters or HMI screens in addition to electronic cards.
Cooling Systems:	The power electronics generate significant heat when in service and there is generally a cooling system used to limit this temperature excursion. There can be issues with coolers such as blockages, leakages etc. that will lead to an increase in electronic temperature, potentially leading to premature failure.
External fault:	The drive electronics are susceptible to external faults which may lead to drive failure or damage. This includes lightning strikes on the equipment itself, or strikes elsewhere leading to disturbances within the electrical system.

4.3 Condition monitoring techniques

The condition monitoring of the individual components such as transformer, circuit breaker etc. are listed in the relevant sections of this document. Condition monitoring of the electronics are limited but the following can be considered:-

Thermography:

Thermography of the panel can be completed to assess the overall temperature profile of the panel and if the cooling system, connection arrangement or other parameters are faulty.

Pressure/Temperature monitoring:

The cubicle cooling temperatures and pressures can be monitored to assess if blockages are developing. It is important to note that the electronic life can be substantially reduced if the temperature increases. In the case of water-cooled systems, system flow rates and coolant conductivity may need to be monitored.

Software monitoring:

The complex software in use in VSDs can also be used for self-diagnosis of faults. Caution should be taken when assessing the robustness of this software given the suddenness of a potential failure in power electronics. Some manufacturers are providing remote drive diagnostic tools for difficult to reach installations (for example offshore).

4.4 Expected / accepted values

Generally the limit to drive life is set by the availability of spare parts and the appropriately skilled technicians, provided that routine maintenance procedures are followed. These factors limit the economic life to about 25 years, at least for small VSDs.

4.5 Assessing risk of failure

A major cause of failure is overheating. Therefore VSDs which may suffer impaired cooling, for example due to a dusty environment which results in frequent clogging of fan filters are particularly at risk.

4.6 Life extension methods

Pre-emptive replacement of limited life (≤ 10 years) components should be built into the maintenance strategy.

Failure rate increases significantly if the power electronics are allowed to overheat. EEMUA Members have found that cooling fan bearing failures are a frequent cause of VSD failure, and furthermore that the failure rate correlates closely with the bearing life. Replacement of internal cooling fans should be considered after 4 years, and forced air cooling fans after 6 years. Door filters should be replaced every year, or more frequently if indicated by inspection.

A useful approach is to clean filters and check fans as part of the basic maintenance regime. This should be supplemented by assessing which are the most critical units on site and running a replacement program rather than “waiting for the failure”.

Capacitor life expectancy is approximately 10 years, governing factors being reduced capacitance of electrolytics due to drying out, and possible insulation failure of all capacitor types due to occasional overstress (design dependant). Electrolytic capacitor failure rate is known to double for a 10 °C rise in temperature^[7]. Capacitors in the firing and DC bus circuits should be replaced every 10-12 years.

Ribbon cables are frequently used within the control electronics and are subject to degradation of their terminations. Replacement after 10 years is recommended.

4.7 Equipment specific useful extras/examples

Component obsolescence is a major issue, due to the short period for which electronic components are recommended for new build. Where a large number of similar VSDs is used it may be feasible to maintain a comprehensive spares holding, but it is likely to be expensive and would need effective management.

Because of the obsolescence issue, and the scarcity of skills associated with fault finding and repairing units using obsolescent components, costs tend to increase with age, to the point that it may be uneconomic to repair a unit which is more than 20 years old. Where only one such unit of a redundant pair has failed, if the failed unit is replaced then replacement of the non-failed unit should also be considered.

5 Electrical protection devices

5.1 Technology introduction

Experience is that old electro-mechanical equipment is reliable but does not provide selectivity. Furthermore, availability of spares is known to be a problem for older equipment. Newer equipment may have the capability to be programmed for particular fault / non-fault scenarios, for example as defined by a current versus time profile. However there are indications that the technology is not yet mature in terms of equipment reliability.

5.2 Typical Failure modes

Increased failure rates are associated with:

- High humidity and high ambient temperature.
- Dusty or dirty atmosphere.
- Corrosive atmosphere.
- Frequent switching operations.
- Frequent fault operations.

Common problems include:

- Simple mechanical failures or misalignments of internal keys, bolts, pins, guides etc, either due to wear and tear, or perhaps due to electromagnetic forces encountered under fault conditions.
- Accumulation of carbon or sludge within the mechanism or on the bushings.
- Flashover damage to the static shield or resistor.
- Burning or erosion of parts or barriers.
- Moisture ingress around bushing gaskets.

Equipment which incorporates control electronics containing electrolytic capacitors is at risk of failure due to their typical failure modes, such as:

- Drying out of electrolyte due to age and elevated temperature – resulting in reduced capacitance.
- Leakage, possibly explosively – due to elevated temperature, voltage surge or marginal ripple current rating – resulting in total failure (usually open circuit).
- Short-circuit failure of solid dielectric tantalum capacitors (this may present a fire risk) – due to voltage or current surges or high temperatures.

Dependence of control electronics on external power, such as a UPS means that the failure modes of that supply also have to be taken into account.

The ability to program protection devices for specific fault scenarios provides great flexibility, but also opens up the possibility of software / firmware glitches which may affect operation in ways which are not obvious from normal testing.

5.3 Condition monitoring techniques

Warning signs would be:

- Charred or burned insulation.
- Darkened or charred terminal leads.

Condition may be monitored using the following parameters:

- Insulation Resistance (IR).
- Pick-Up (Induction disc. and/or instantaneous unit).
- Time characteristics or trimming test (when applicable).
- Target and seal-in operation.
- Special tests that are peculiar to the specific type of relay such as through fault, reach, dropout, etc.

Monitoring of relay watchdog output contact, wired to a manned location or annunciator is also useful.

There is no effective method of predictive maintenance for electronic devices.

5.4 Expected / accepted values

These tend to be specific to a particular device type or application. Manufacturers' documentation should be referred to.

5.5 Assessing risk of failure

Interrupter switches with fault-clearing capability are quite sensitive to the manufacturer's design rating number of duty cycles. Effects of any overstress need careful evaluation and are likely to result in premature replacement.

5.6 Life extension methods

Frequency of maintenance:

Maintenance should be every 2–3 years, more often where dust, moisture, corrosion, vibration, or wide temperature variation is present. Where the environment and operating conditions are favourable it may be sufficient to test and not do any routine maintenance. Follow manufacturer's instructions for each type of relay and test set.

Specialist maintenance methods:

Comparison of test results with a library of comparable relays.

Post fault reassessment of equipment:

Do function checks at every major outage.

Carry out cleaning, calibration and function tests.