Appendix 1.16: Initiative AM13 FMEA project audit

Regulatory proposal for the ACT electricity distribution network 2019-24
January 2018

Disclaimer: On 1 January 2018, the part of ActewAGL that looks after the electricity network changed its name to Evoenergy. This change has been brought about from a decision by the Australian Energy Regulator. Unless otherwise stated, ActewAGL Distribution branded documents provided with this regulatory proposal are Evoenergy documents.

INITIATIVE AM13 – FINAL REPORT
FAILURE MODE EFFECTS ANALYSIS
PILOT PROJECT

Version number 1.1 : Effective date: 28 May 2015

Version Control

Date	Version No.	Author	Description of Change
	0.1	[redacted]	Initial draft for comment
8/05/2015	1.0	[redacted]	Recommended changes by [redacted]
28/05/2015	1.1	[redacted]	Comments by [redacted]

Related Documents

	Title	Reference
A	INITIATIVE AM13 - PROJECT BRIEF FAILURE MODE EFFECTS ANALYSIS PILOT PROJECT	Initiative AM13 of Staying Number 1 suite of projects
B		

Document Authorisation

Endorsed	[redacted]
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Purpose of Report

This is the final report for completion of initiative AM13, a pilot project to apply Failure Modes and Effects Analysis (FMEA) to zone substation High Voltage (HV) circuit breakers. This report:

- provides a recap of the project background and objectives;
- summarises the outcomes of the project, including potential savings;
- provides an assessment of the outcomes against the initial project objectives;
- recommends a revised maintenance program for zone substation HV circuit breakers;
- recommends an analysis and investigation into implementation of FMEA on other suitable assets;
- seeks authorisation to implement the recommendations; and
- provides comprehensive results of the FMEA in the appendix.

Background

FMEA is a systematic, proactive method for evaluating a maintenance process to identify where and how assets might fail, to assess the relative impact of different failures, in order to identify the elements of the maintenance process that require most attention.

The full range of benefits from implementing FMEA are better achieved by completing them on complex and critical assets which are comprised of a number of sub-systems (high voltage circuit breakers and power transformers), where the failure types and their frequencies cannot be easily identified.

Circuit breakers have been chosen as an appropriate asset for this pilot study because of their criticality, technical complexity, and the high risk of failure to open within the specified time under fault conditions which can cause collateral damage to other network assets.

Criticality of customers such as hospitals, airport, parliament house, life support systems, water and waste-water treatment plants and similar have been considered to formulate an appropriate maintenance strategy to ensure higher levels of supply reliability required for these customers.

Project Objectives

The objectives of this pilot project are to:

- Implement FMEA as a reliable tool for improving strategic processes thus reducing maintenance effort.
- Identify and quantify potential savings in the life cycle management of the 132 kV, 66 kV and 11 kV zone substation circuit breakers.
- Explore options to improve asset reliability and availability by identifying, analysing, and improving the management of their high-risk components. Reliability and availability are appropriate metrics for maintenance efficiency.
- Another objective of this pilot is to estimate potential improvements in reliability and availability of the circuit breakers in the study. An investment of nearly $65,000 has already been made in purchasing testing equipment (circuit breaker analyser) for regular condition assessment of the circuit breakers.
- Consider the most appropriate path to develop the FMEA study into a complete Reliability Centred Maintenance (RCM) strategy for potential improvements in extending and sustaining the reliability of the asset.
- Update zone substation circuit breaker Asset Specific Plan (ASP) and related maintenance procedures with prudent and proactive maintenance, and condition assessment tasks that identify, monitor and address the failure modes earlier in the process when they are less expensive to fix.
- Update Program of Works (PoW) for 2015/16 & onwards.

Project Outcomes

Technical Findings

The FMEA process disclosed a number of potential failure modes, root causes and subsequent remedial activities to reduce the risk of failure to acceptable levels. The categories of circuit breakers analysed are shown in table 1. Out of a total of 404 circuit breakers, over 83% are 11 kV, and over 52% are vacuum insulated 11 kV. The vacuum insulated circuit breakers are recent technology, high reliability and low maintenance, therefore consideration should be given to an economic life cycle replacement analysis on the remaining 31% of oil insulated circuit breakers to determine when, and on what basis they can be replaced should an opportunistic event occur. All new 11 kV circuit breakers are vacuum insulated.

The 132 kV circuit breakers form nearly 16% of the fleet, the most problematic being the 15 pneumatically actuated SF_6 insulated breakers because of their high SF_6 content, propensity to leak, the need for regular inspections, and obsolescence. There is a long term replacement program for these breakers. The fleet contains only 5 of the 66 kV circuit breakers, located at Fyshwick zone substation, and these are a special case. Fyshwick is considered to be a temporary substation, however in the recent past it has benefitted from a new 66kV power transformer ($1.3M) with replacement of 66 kV line side current transformers ($350k) currently under implementation and new weld-mesh fencing worth about $1.5M under consideration. There are no firm plans for either de-commissioning of the Fyshwick zone substation or its long term sustainable life cycle management. In view of this, it is recommended that the condition of all 5 of the 66 kV circuit breakers at Fyshwick ZS should be analysed as a matter of urgency to gain an understanding of the risk they present, and form long term maintenance and, if appropriate, replacement plans.

Table 1 – Summary of zone substation circuit breakers

Insulating medium	Operating mechanism	Operating voltage (kV)	Quantity	%
Vacuum	Spring	11	212	52.5
Oil	Solenoid	11	124	30.7
Oil	Spring	66	5	1.2
Oil	Spring	132	37	9.2
SF_6	Pneumatic	132	15	3.7
SF_6	Spring	132	11	2.7
		Total	404	100

11kV Oil Circuit Breakers – Solenoid Actuated

A review of the 11kV Oil Circuit Breakers – Solenoid Actuated, yields the following potential failure mechanisms and recommended remedies:

1. **Incorrect type of lubrication & frequency (not often enough or too much):** Review and update the maintenance procedure by an investigation to determine

and specify the correct lubricant and create a check-list within the procedure to ensure quality lubrication. This includes a procedure specifies proper degreasing and application of the correct lubricant in the proper manner.

2. **Mechanical misalignment due to incorrect assembly**: When servicing the circuit breaker, maintain tolerances as specified in manufacturer's manuals and /or drawings. Use circuit breaker analyser after re-assembly to ensure performance is still within tolerance. Procure or make special tools for circuit breaker re-assembly. Provide maintenance training by experienced mechanics, and ensure competency of all circuit breaker maintenance personnel.
3. **Incorrect operation during racking in & out:** Update the procedure, highlighting the "racking in & out" process needs to be completed with due care and attention. Provide maintenance training by experienced mechanics, and ensure competency of all circuit breaker maintenance personnel.
4. **DC secondary burnt off wiring; blown fuse, DC CB tripped, crimps come off, faulty wiring, hot joint, obsolete RTU's and transducers, SCADA issues:** Update procedure to ensure closing relay is of correct rating and is not fused. Thermo-scan the control circuitry to ensure that there are no hot spots in the control cabinet. Conduct a close visual inspection of control wiring to ensure no burn marks, or discoloured wiring. Check for burnt odour.
5. **Blown circuit fuses:** Investigate the option of monitoring the circuit fuses. There is also the option of monitoring the fuses in a series circuit resulting in a single fail signal to reduce the cost of SCADA configuration.
6. **Fatigued opening mechanism:** Include a "first trip" analysis in the procedures. Conduct a visual inspection of the opening mechanism, including manufacturer's recommended checks, for example check the opening spring length.
7. **Incorrect protection setting (mal-grade):**Test protection relays and upstream relays. Conduct a comprehensive desktop protection study to ensure correct protection gradings have been applied.
8. **Lack of knowledge base & training:** Conduct competency based training from Original Equipment Manufacturer (OEM), or experienced mechanics.

11kV Vacuum Circuit Breakers

A review of the 11 kV Vacuum Circuit Breakers yielded no new potential failures beyond those that were already detected during the11 kV Oil Circuit Breaker analysis, with an RPN greater than 200.

132 kV Minimum Oil type Circuit Breakers – Spring Actuated

1. **Corrosion due to failure of chamber seals:** Introduce regular program of checking for cabinet leaks.
2. **Burnt out fuse holder:** Thermo-scan the control circuitry to ensure no hot spots are present in the control cabinet. Conduct a close visual inspection of control wiring to ensure that there are no burn marks, or discoloured wiring. Check for burnt odour.
3. **Blown circuit fuses:** Investigate the option of monitoring the circuit fuses. There is also the option of monitoring the fuses in a series circuit resulting in a single fail signal to reduce the cost of SCADA configuration.
4. **Fatigued opening mechanism:** Include a "first trip" analysis in the procedures. Conduct a visual inspection of the opening mechanism, including manufacturer's recommended checks, for example check the opening spring length.
5. **Corrosion due to failure of anti-condensation heater**: Conduct a regular check of the condensation heater functionality. Select manual mode and check current draw with a clamp meter.
6. **Corrosion due to failure of cabinet seals:** Introduce a seal replacement program in conjunction with other works (opportunistic).
7. **Mechanical misalignment due to incorrect assembly:** Maintain tolerances as specified in manufacturer's manuals and/or drawings. Use the circuit breaker analyser after re-assembly. Procure or make special tools required for circuit breaker re-assembly. Ensure training for maintenance of circuit breakers under experienced mechanics.
8. **Lack of knowledge base & training:** Conduct competency based training from OEM, or experienced mechanics.

132 kV SF_6 type Circuit Breakers – Spring & Pneumatic Actuated

A review of the 132 kV SF_6 circuit breakers yielded potential failures similar to minimum oil breakers, with the same recommended remedies. These breakers are also subject to SF_6 leakage, however the procedures currently in place for this potential failure mode are already sufficiently robust to keep the RPN below 200.

Revised Maintenance Schedule & Procedure

Improvements in maintenance quality, as suggested in the above Technical Findings clauses provide the opportunity to reduce maintenance frequency whilst targeting and improving risk management. Rationalisation of the maintenance schedule facilitates further savings by aligning maintenance into periods with a convenient lowest common denominator, thereby saving on duplicated travel and setup costs, as well as duplicated outages. A summary of the recommended maintenance schedules for the differing circuit breaker types is listed below:

11 kV Oil Circuit Breakers: Remain on 4 year maintenance period, extend fault interruptions from 5 to 6. Conduct condition monitoring, including first trip measurement & analysis, timing (open & close), coil currents, and Dynamic Resistance Measurement (DRM). Follow with overhaul if required.

11 kV Vacuum Circuit Breakers: Extend 7 year maintenance period to 8 years, with 10 fault interruptions (whichever occurs first). Conduct condition monitoring, including first trip measurement & analysis, timing (open & close), coil currents, and DRM. Follow with overhaul if required.

66 kV Oil Circuit Breakers: The condition of these circuit breakers is not known. Conduct condition monitoring on all these breakers as soon as possible, including first trip measurement & analysis, timing (open & close), coil currents, and DRM. Follow with overhaul if required. Prepare maintenance schedule based on the findings.

132 kV Minimum Oil Circuit Breakers: Remain on 8 year maintenance period, or maximum 3 fault interruptions. Prior to any maintenance, conduct condition monitoring, including first trip measurement & analysis, timing (open & close), coil currents, and DRM. Follow with overhaul if required.

132 kV SF_6 Circuit Breakers: Remain on 8 year maintenance period, or maximum 30 fault interruptions. Conduct condition monitoring, including first trip measurement & analysis, timing (open & close), coil currents, and DRM. Follow with overhaul if required. Pursue an opportunistic replacement program of the obsolete Hitachi pneumatically actuated breakers.

Financial Implications

11 kV Oil Circuit Breakers: The average annual planned maintenance cost for this class of breaker is $44,750, for 124 breakers, this implies and average cost of $361 per breaker, per annum. If a breaker lasts the 4 year cyclic period before requiring maintenance, the savings achieved are nil. If the breaker reaches 6 faults in the 4 year cycle the savings would be $60 per breaker per annum. At the end of the 4 year period, if analysis of the breaker indicates an overhaul is not required, savings are the difference between a test and an overhaul, estimated at $180 (half the cost) per annum per breaker. In the absence of detailed statistical data on the occurrence rate of these 3 events, assuming each event has an equal probability of occurring, then expected savings per breaker are:

$0/3 + $60/3 + $180/3 = $80 per breaker per annum

= $9,944 per annum (all breakers)

11 kV Vacuum Circuit Breakers The average annual planned maintenance cost for this class of breaker is $16,842, for 212 breakers, this implies and average cost of $79 per breaker, per annum. If a breaker lasts the 8 year cyclic period before requiring maintenance, the savings achieved are $10 per breaker per annum. If the breaker reaches 10 faults in the 8 year cycle the savings would be nil. At the end of the 8 year period, if analysis of the breaker indicates an overhaul is not required, savings are the difference between a test and an overhaul, estimated at $40 (half the cost) per annum per breaker. In the absence of statistical data on the occurrence rate of these 3 events, assuming each event has an equal probability of occurring, then expected savings per breaker are:

$10/3 + $0/3 + $40/3 = $17 per breaker per annum

= $3,509 per annum (all breakers)

66 kV Oil Circuit Breakers The average annual planned maintenance cost for this class of breaker is $3,167 for 5 breakers, this implies and average cost of $633 per breaker, per annum. If a breaker lasts the 4 year cyclic period before requiring maintenance, the savings achieved are nil. The condition of these circuit breakers is not known. The recommended action is to conduct condition monitoring on all these breakers as soon as possible, including first trip measurement & analysis, timing (open & close), coil currents, and DRM. Follow with overhaul if required. The ongoing maintenance costs will be available after preparation of the maintenance schedule based on the condition assessment findings.

132 kV Minimum Oil Circuit Breakers The average annual planned maintenance cost for this class of breaker is $24,688, for 37 breakers, this implies an average cost of $667 per breaker, per annum. If a breaker lasts the 8 year cyclic period before requiring maintenance, the savings achieved are nil. If the breaker reaches 3 faults in the 8 year cycle the savings would be nil. At the end of the 8 year period, if analysis of the breaker indicates an overhaul is not required, savings are the difference between a test and an overhaul, estimated at $334 (half the cost) per annum per breaker. In the absence of statistical data on the occurrence rate of these 3 events, assuming each event has an equal probability of occurring, then expected savings per breaker are:

$0/3 + $0/3 + $334/3 = $111 per breaker per annum

= $4,115 per annum (all breakers)

132 kV SF_6 Circuit Breakers The average annual planned maintenance cost for this class of breaker is 19,253, for 26 breakers, this implies and average cost of $741 per breaker, per annum. If a breaker lasts the 8 year cyclic period before requiring maintenance, the savings achieved are nil. If the breaker reaches 30 faults in the 8 year cycle the savings would be nil. At the end of the 8 year period, if analysis of the breaker indicates an overhaul is not required, savings are the difference between a test and an overhaul, estimated at $370 (half the cost) per annum per breaker. In the absence of statistical data on the occurrence rate of these 3 events, assuming each event has an equal probability of occurring, then expected savings per breaker are:

$0/3 + $0/3 + $370/3 = $112 per breaker per annum

= $3,209 per annum (all breakers)

Total expected planned maintenance savings on all classes of circuit breakers = $20,777 which represents 19.1% of the average budget of $108,699.

Average annual unplanned maintenance expenditure on circuit breakers was $326,016, (for financial years 2011/12 to 2013/14). Savings on unplanned maintenance will depend on the effect of the revised planned maintenance schedule and the resultant rate of random failures, however the optimal expenditure is expected to be where unplanned expenditure is close to planned expenditure.

Total expenditure on this initiative to date has been less than $10,000 on consulting expenses plus time spent by staff in attending workshops and preparing reports and presentations.

Intangible Benefits

Aside from immediate financial benefits, improvements in the quality of circuit breaker maintenance will result in a number of intangible benefits, which will in turn lead to improved corporate performance. These benefits are listed as follows:

1. Higher quality maintenance has the potential to initiate a virtuous circle by freeing up time and resources to further improve maintenance quality and resulting reliability.
2. Improved maintenance will result in a higher ratio of planned / unplanned maintenance and therefore better resource control.
3. The demand imposed by insisting on higher quality maintenance will result in staff skills improvement.
4. Emphasis on quality and alignment of activities with corporate objectives will result in an improvement in staff morale and encourage self-motivation.
5. Evidence based superior maintenance derived from reliable information from experienced staff will provide management with assurance on the quality of the outcomes.
6. Transparency of maintenance program design and scheduling will result in better acceptance and understanding of the maintenance regime.

Assessment against Objectives

1. Implement FMEA as a reliable tool: This objective has been met. Further assets have now been selected for FMEA with a view to optimising the maintenance schedule.
2. Identify and quantify potential savings: This objective has been met. The savings are documented in this report.
3. Potential improvements in reliability and availability: This objective has been met. A number of improvements in maintenance procedures have been identified which should lead to potential improvements in reliability and availability.
4. Update zone substation circuit breaker Asset Specific Plan (ASP) and related maintenance procedures: This objective is currently in progress.
5. Update PoW for 2015/16 & onwards: This objective is currently in progress.

Recommendations

The following recommendations have been made as a consequence of the implementation of AM13 and subsequent findings:

Changes to Riva

Embed the risk tables used in the generation of the FMEA data sheets within the asset specific plan template in Riva.

Align the RPN calculations in Riva with those used within this initiative.

Update the Zone Substation Circuit Breaker Asset Specific Plans and maintenance strategies to reflect the Technical Findings in this report. This will also update the Program of Works.

Zone substation circuit breakers

Implement the changes to the zone substation circuit breaker maintenance procedures and schedules as detailed in the Technical Findings of this report.

FMEA on other Critical Assets

Asset managers were asked to nominate a selection of Asset Types for further FMEA based on the following criteria:

- Asset criticality – based on potential effects of failure: Financial, Operations (loss of supply), Reputation, Health/ safety, Environment, Legal/ compliance, Program/ project
- Current asset reliability
- Current effort to support reliability, efficiency of that effort, and potential for improvement (for example programmed fault finding for hidden failures)
- Risk of obsolescence and potential for technological step change in performance
- Current OPEX expenditure
- Asset replacement value and proximity to end of economic life
- Probability of successful application of FMEA to the asset
- History of previous analysis (or lack of) on that asset class

Subsequent to the nomination process and a combined workshop with the asset managers, the following asset classes were determined to be suitable for analysis:

1. Zone Substation Power Transformers
2. Zone Substation Tap Changers/Diverter Switches
3. Zone Substation and Distribution Batteries

4. Distribution Hazemeyer Switchgear & its cable terminations
5. Distribution Air break switches
6. Distribution Surge diverters
7. Secondary Systems 11kV zone feeder protection – includes all components in protection system
8. Secondary Systems 132kV line distance protection – includes all components in protection system
9. Secondary Systems 132/11kV Transformer protection – includes all components in protection system

Appendix A: Risk Tables (Severity, Occurrence & detection)

SEVERITY of Effect	Ranking
Hazardous-without warning: Very high severity ranking, potential failure mode affects safety, noncompliance with policy and without warning.	10
Hazardous-with warning: Very high severity ranking, potential failure mode affects safety, noncompliance with policy with warning.	9
Item inoperable, with loss of primary function.	8
Item operable, but primary function at reduced level of performance.	7
Equipment operable, but with some functions inhibited	6
Operable at reduced level of performance.	5
Does not conform. Defect obvious.	4
Defect noticed by routine inspection.	3
Defect noticed by close inspection.	2
No effect	1

PROBABILITY of Failure	Failure Rates	Ranking
Very High: Failure is almost inevitable	**Very High:** Failure is almost inevitable Possible Failure Rate >=1 every week	10
	Very High: Failure is almost inevitable Possible Failure Rate 1 every month	9
High: Repeated failures	**High:** Repeated failures Possible Failure Rate 1 every 3 months	8
	High: Repeated failures Possible Failure Rate 1 every 6 months	7
Moderate: Occasional failures	**Moderate:** Occasional failures Possible Failure Rate 1 every year	6
	Moderate: Occasional failures Possible Failure Rate 1 every 3 year	5
	Moderate: Occasional failures Possible Failure Rate 1 every 5 years	4
Low: Relatively few failures	**Low:** Relatively few failures Possible Failure Rate 1 every 8 years	3
	Low: Relatively few failures Possible Failure Rate 1 every 15 years	2
Remote: Failure is unlikely	**Remote:** Failure is unlikely Possible Failure Rate <=1 every 20 years	1

Detection	Likelihood of DETECTION	Ranking
Absolute Uncertainty	Control **cannot** prevent / detect potential cause/mechanism and subsequent failure mode	10
Very Remote	**Very remote** chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	9
Remote	**Remote** chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	8
Very Low	**Very low** chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	7
Low	**Low** chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	6
Moderate	**Moderate** chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	5
Moderately High	**Moderately High** chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	4
High	**High** chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	3
Very High	**Very high** chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	2
Almost Certain	Control **will** prevent / detect potential cause/mechanism and subsequent failure mode	1

Appendix B: FMEA Data Sheets