Rapid Earth Fault Current Limiter (REFCL) Program

Primary Asset Hardening Strategy

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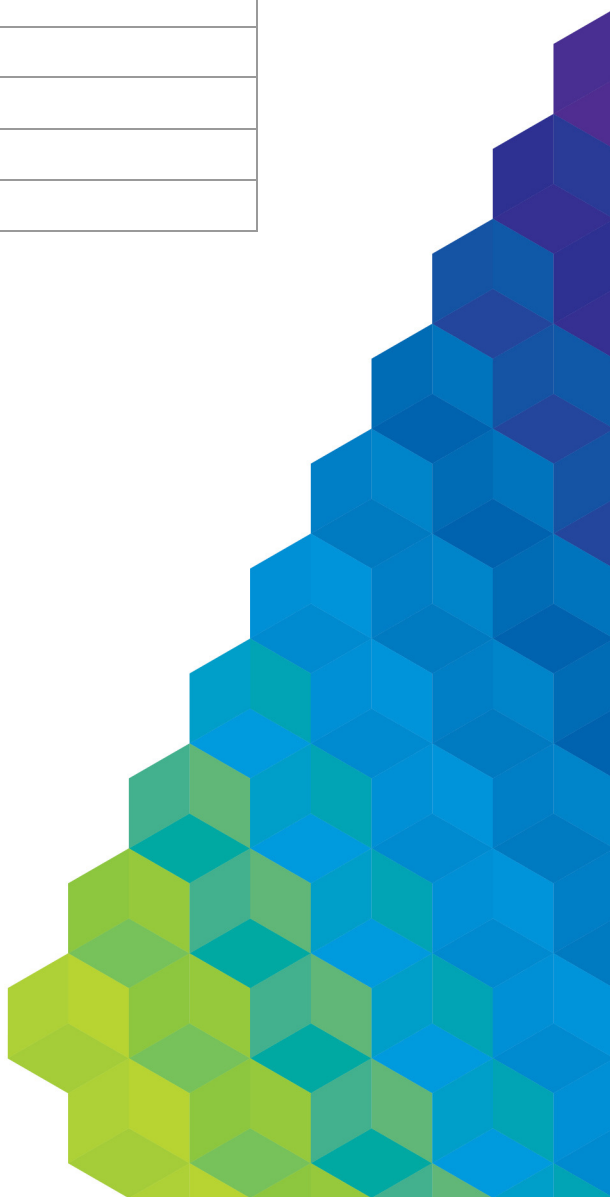

REVISION HISTORY

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Contents

1 PURPOSE AND BACKGOUND

1.1 Purpose

The purpose of this supporting document is to explain AusNet Services' primary asset hardening strategy, which addresses the voltage stress that occurs on 22kV primary equipment within zone sub-stations when a Rapid Earth Fault Current Limiter (REFCL) responds to a phase to ground earth fault.

REFCLs are to be installed on AusNet Services' network in response to new bushfire mitigation regulations. Primary asset hardening work is one of the work streams that comprise the REFCL installation program.

1.2 Background

AusNet Services' network operates in a unique geographical location, some of which is exposed to extreme bushfire risk. These conditions warrant significant investment to mitigate the risk of bushfires as a result of earth faults on the distribution network risk.

The 2009 Victorian Bushfire Royal Commission made several recommendations with respect to fires initiated from distribution electricity networks. Subsequently, the Victorian Government established the Powerline asset Bushfire Safety Program to research the optimal way to deploy REFCLs for bushfire prevention. This research led the Government to introduce Electricity Safety (Bushfire Mitigation) Amendment Regulations 2016.

For AusNet Services, the regulations require each polyphase electric line originating from 22 selected zone substations to comply with mandated voltage reduction performance standards by 1 May 2023. In the timeframes specified in the regulations, the installation of REFCLs is the only feasible technological solution.

The REFCL installation program will be managed in three Tranches. This strategy document is expected to remain valid for all three Tranches however any changes to the strategy as a result of REFCL Program deployment learnings will be captured as a revision to this document.

The 'primary asset hardening' work stream is concerned with the high voltage and condition assessment testing of primary equipment that will be directly affected by the increased voltages imposed by the new REFCL technology. This is a once-off set of condition assessment tests attempting to identify an asset's capability of withstanding the over-voltages that will imposed on that asset during the operation of a REFCL device.

Primary 22kV assets considered within this strategy are those contained within a zone sub-station

- Power transformers
- Stand-alone Circuit Breakers
- Current and Voltage Transformers
- Indoor Switchboards
- Capacitor Banks
- Surge Arrestors within stations
- Station Service Transformers
- Air Insulated Switchgear (AIS) and Busbars
- Medium Voltage Cables (either connecting assets within the station or feeder exits)
- REFCL GFN

- Surge Arrestors on overhead lines (are detailed in REF 20-07 Compatible Equipment – Line Hardening Strategy)

Primary equipment fitted to a REFCL protected network (high impedance earthing) must be capable of sustaining the elevated voltages that occur on healthy phases in response to a phase to ground fault.

Sustained over-voltages will be experienced regularly and repeatedly during REFCL operation.

1.3 Strategy Objective

The objective of this primary asset hardening strategy is to:

- describe the issues associated with the operation of the different asset types on a network utilising REFCLs; and
- demonstrate that a prudent and efficient approach has been taken to the selective replacement of primary assets on AusNet Services' network.

1.4 Definitions - References

Medium Voltage (MV)	Working voltage 3.3kV up to and including 33kV
Condition Assessment (CA)	A program of tests to determine the condition of a primary asset
SMI 12-01-02	AusNet Services Standard Maintenance Instruction for cable commissioning protocols
REF 20-07	REFCL Program – Line Hardening Strategy

2 Investment Need

The Electricity Safety (Bushfire Mitigation) Amendment Regulations (2016) specify the installation and operation of the voltage reduction required on a polyphase primary asset when a phase-to-ground fault occurs, and the fault current levels that must be achieved. These specifications can only be met safely where under-rated primary asset equipment are replaced.

The need for this 'primary asset hardening' investment was highlighted in the REFCL trials:

> *"When an earth fault occurs, the REFCL response creates voltage stress on network equipment connected to un-faulted phases, which can lead to a second fault. Outcomes can be worse than if a REFCL were not installed.[1] "*

The 'second fault' results from the exposure of primary equipment to the high voltages that arise from REFCL operation. These 'second faults' are also known as 'cross country faults' i.e. they occur at a location on the feeder other than the site of the initial fault which caused the REFCL to operate.

As noted in the above excerpt, the outcome of the second fault can be worse than if a REFCL were not installed due to the potential for both the original fault and the failing primary asset to ignite a fire. Furthermore, the REFCL will not operate when two faults have occurred on the network and therefore no protection is provided by the REFCL following the second fault. It is therefore imperative that incompatible primary assets are replaced through a systematic 'primary asset hardening' work stream as part of the REFCL installation program.

[1] Dr Anthony Marxsen, REFCL Trial: Ignition Tests, Marxsen Consulting Pty Ltd, Monday 4 August 2014, page 93.

3 Options Analysis and Preferred Approach

The installation of REFCLs on the existing network requires the establishment of a cost effective method to replace primary assets to achieve compliance with the Regulations. As already noted, this work is essential for REFCL technology to operate safely i.e. to operate without increasing the likelihood of bushfire ignition.

AusNet Services' primary station assets must now cater for sustained elevated phase to ground voltages up to 24.2kV (i.e. 22kV plus 10%).

The following activities have been completed in order to evaluate options:

- Desktop and field identification of the different primary asset types and population currently on the network; and
- A staged asset condition assessment program to identify assets that might be prone to failure when exposed to elevated voltages.

Type testing has occurred on some of the primary assets against their designed operating and over-voltage insulation levels, whilst ensuring no excessive Partial Discharge or thermal runaway exists when subject to the new voltage requirements. The objective of this testing is to minimise the risk of failure either during or following REFCL operation.

From these tests, a more detailed inspection and test program has been developed for the different assets. In particular, this is in reference to switchboards, power transformers and underground cables. For the other primary assets, assessment test programs are still yet to be developed.

The option of removing, rather than replacing, some primary assets was not evaluated as typically the primary asset has a set function to perform in that position within the network. Straight removal of an asset would potentially require a reconfiguration of the network. Therefore the approach of assess and replace as required was adopted.

A summary of our analysis in relation to each of these options is shown in Table 1.

Table 1: Options evaluated

Option	Advantages	Disadvantages
1. Identify primary assets not capable of withstanding the elevated voltages (based on test results) and replace accordingly.	Ensures REFCL operating compliance on a risk-based approach. Reduces volume of work required. Ensures cost efficiency.	Risk still exists of failure within a substation should primary assets be incorrectly identified or missed during replacement program.
2. Replace all primary assets.	Uniform approach. One hundred percent replacement of primary assets would reduce the risk associated with primary assets being missed during the planning and delivery stages of the project.	Inhibitive cost increase to the project. Increased volume of work. Fails to maximise community benefits. Typically not necessary for air insulated equipment.
3. Allow existing primary assets to fail when exposed to REFCL operating	Less up-front capex.	Likely to result with increased risk of fire (defeating the purpose of the REFCL program) and

Option	Advantages	Disadvantages
voltages.		hence reduced public safety. Poor network reliability would result due to potentially multiple unplanned outages from a fault within a critical asset. Has the potential to black out areas depending on which primary asset is affected. Negative reputational impacts.

Option 1 is the preferred option due to:

- It is the lowest cost option, providing that the risk of station faults can be mitigated;
- It is strongly preferred to Option 3, which exposes the community to unacceptable safety risks and reliability outcomes; and
- Meets the objective for safe compatible operation with REFCL technology.

Assets excluded from Option 1 include:

- Station service transformers. Refer Section 4.7
- All HV customer owned assets

3.1 Preferred Option Risks

The key risk associated with replacing only tested primary assets is that the risk of other non tested assets failing still exists. Although a pragmatic approach has been taken, primary assets may be missed in the replacement works, unless the entire population is tested. This risk is reduced by voltage stress testing during the commissioning phase of the REFCL.

A further risk arises from selecting primary assets to be replaced utilising type testing. It is possible that some primary assets that passed the type testing will fail in operation or that the representative sample is not truly representative. Undertaking a type test is done by making certain assumptions about the condition of the untested assets. This risk has been reduced, in some cases, by selection of the asset in the 'worst' condition.

4 Primary Assets Hardening Requirements

Wanting to avoid both asset failures and extended unplanned outages to customers as a consequence of REFCL operation, a cost effective Condition Assessment (CA) program was established for all primary assets that will be affected by REFCL over-voltages.

Primary assets within the stations and all Medium Voltage cables impacted by the REFCL program have been identified through a desktop audit with a CA completed as per internal procedures and policies.

HV condition assessment testing may not be warranted if any of the following can be satisfied

- a CA program has been undertaken on the asset within the last 5 years
- a CA program has been undertaken on a similar unit, acting as a 'type' test
- a physical inspection of the asset verifies that the asset appears to be fit to withstand the REFCL over-voltages

Although the manufacturer may indicate the design is suitable to withstand REFCL voltages, the operating environment of each asset may dictate that assessment testing is required.

Partial Discharge (PD) activity within a primary asset insulation medium can be detrimental to the service life of the asset. The need for CA tests, if not obvious may need to be determined in consultation with the SME within Network Engineering.

4.1 Power Transformers

Typically, the design of a power transformer is such that it will be able to withstand the REFCL voltages. Notwithstanding that, the following points shall be addressed

- Condition and rating of the LV Neutral bushing and connection cable
- Condition and rating of the LV phase bushings
- The age and in-service deterioration of a transformer can affect its ability to withstand the designed over-voltages. When doubt exists, the SME shall be consulted.

When required, the following tests shall be undertaken in consultation with the SME within Network Engineering who will verify the test voltage levels and test duration.

- Insulation Resistance : Each bushing to earth (2.5kVdc for 1 minute)
- Insulation Resistance : Each winding to earth (2.5kVdc for 1 minute)
- Overvoltage & PD on LV Neutral bushing
- Overvoltage & PD on main windings
- Overvoltage and DDF tests on bushings

Test results shall be scrutinised by the SME to determine the suitability of the asset.

4.2 Stand-alone Circuit Breakers

Typically, the design of an outdoor CB is such that it will be able to withstand the REFCL voltages. Notwithstanding that, the following points shall be addressed

- For Bulk Oil outdoor CBs and Minimum Oil (outdoor & indoor) CBs
  Check the Condition of the CB internals, oil contamination and sludge build-up, etc.
  Clean and refurbish as required
- Condition and rating of the Bulk oil CB bushings

When required, the following tests shall be undertaken in consultation with the SME within Network Engineering who will verify the test voltage levels and test duration.

- Insulation Resistance : Each bushing to earth (2.5kVdc for 1 minute)
- Overvoltage and DDF tests on bushings

Test results shall be scrutinised by the SME to determine the suitability of the asset.

4.3 Current and Voltage Transformers

Typically, the design of an instrument transformer (IT) is such that it will be able to withstand the REFCL voltages. However the age and in-service deterioration of an IT can affect its ability to withstand the designed over-voltages. When doubt exists, the SME shall be consulted.

Notwithstanding that, the following points shall be addressed

- Condition and rating of the IT (and particularly VT's overvoltage factor rating)
  General inspection and evaluation of design parameters
- Position of the IT, it may be located within a circuit that cannot withstand an overvoltage

For example within a power transformer where the rating is 22kV ph-ph

- Single or three phase ITs have different insulation classes

When required, a test program shall be derived on a case by case basis and undertaken in consultation with the SME within Network Engineering. The SME will verify the test voltage levels and test duration.

Test results shall be scrutinised by the SME to determine the suitability of the asset

4.4 Indoor Switchboards

Typically, the design of an indoor switchboard is such that it will be able to withstand the REFCL voltages. However the age and in-service deterioration of a switchboard can affect its ability to withstand the designed over-voltages. The following points shall be addressed

- Enquire of manufacturer as to suitability of design to continuously withstand REFCL voltages

When required, the following tests shall be undertaken in consultation with the SME within Network Engineering who will verify the test voltage levels and test duration.

- All switchboard components are to be thoroughly cleaned prior to testing. Contamination on busbars, stand-off insulators and bushings can cause false-positive test results.
- Insulation Resistance : Each busbar to earth (5kVdc for 1 minute)
- Overvoltage with PD monitoring

  Each busbar to earth (1.0Uo to 1.9Uo in 0.1Uo steps for 30 secs at each level)
- Insulation Resistance Repeat : Each busbar to earth (5kVdc for 1 minute)

Test results shall be scrutinised by the SME to determine the suitability of the asset.

4.5 Capacitor Banks

Typically, the design of an older capacitor bank is such that it will NOT be able to withstand the REFCL voltages, in that the Neutral point of the 'capacitor can' arrangement must remain earthed. An acceptable design to allow REFCL operation requires capacitor cans to have two bushings and the capacitor can to be insulated from ground potential. This will require a complete redesign of non-compliant capacitor banks.

If the existing capacitor bank is of a compatible design, the following points need to be addressed

- Condition and rating of the post insulators
- Condition and rating of the connection cables and terminations
- Condition and rating of the step switches
- Condition and rating of the capacitor cans
- Design of Cap bank Neutral to ensure it is ungrounded

When required, the following tests shall be undertaken in consultation with the SME within Network Engineering who will verify the test voltage levels and test duration.

- Overvoltage on connection cables
- Overvoltage on step switch and their enclosure

Test results shall be scrutinised by the SME to determine the suitability of the asset.

4.6 Surge Arrestors within Stations

Surge Arrestors (SAs) within stations are not required to maintain a bushfire class rating as are their counter-parts on the lines outside of the station boundary. Any replacement program involving SAs within a station shall instigated from the desktop audit where it will be determined if they are designed to withstand the REFCL voltages. No CA testing is required.

4.7 Station Service Transformers

The existing station service transformers are not sufficiently rated to supply the power requirements during REFCL operation and require replacement. The new Station Service Transformers that have a larger power rating have also been designed to ensure that they can withstand the applied REFCL over-voltages.

4.8 Air Insulated Switchgear (AIS) and Busbars

Typically, the design of an AIS and/or outdoor busbar system is such that it will be able to withstand the applied REFCL over-voltages to ground from an insulator creepage distance point of view. However, the air gap clearance to ground may be insufficient due to support structure designs. The following points need to be addressed

- Condition and rating of the post insulators
- Visual confirmation that sufficient clearance exists to the surrounding structures. If doubt exists, a physical measure should be undertaken to confirm the set-up.

4.9 Medium Voltage Cables

The majority of MV cables throughout the distribution network have little or no up-to-date Condition Assessment data. Rather than just undertaking a bulk replacement program of these unknown risks, it has been decided that all ‘critical’ cables that will be exposed to over-voltage conditions during REFCL operations shall be CA tested.

Critical cables are defined as ones where a failure would have an unacceptable effect on

- Number of Customers: backbone (and future backbone)
- Network contingency
- Energy at risk
- Supply agreements
- Power transfer
- Connection points

Therefore they shall include but not be limited to

- Cables from any category in the above list
- All cables connected to power transformer phase bushings (ie not NER, GFN cables)
    - Power transformer Neutral cables only require a HV withstand test.
- All non-switchable Bus-Tie cables
- All Feeder Exit cables (from stations)

As it is nearly impossible to describe all possible cable configurations found on the network, the project manager or commissioning engineer at a particular site can deem a cable to be critical if they see fit, using the above list as a minimum requirement

The CA program shall consist of both on-line and off-line tests

- The following **on-line** tests shall be undertaken

Test	Expected Outcome
Visual Inspection	No obvious signs of significant deterioration and/or damage
PryCam	On-line spot partial discharge measurements to be used as a quick pass/fail measurement on each cable looking for PD/no PD at service voltage

Should either of these tests reveal either physical deterioration and/or PD activity, the off-line testing program could be over-stepped, jumping directly to the asset replacement option, saving the CA testing time and expense

- The following **off-line** tests shall be undertaken

Test	Testing for	Typical Acceptance Criteria
Sheath Integrity	Integrity of outer protection sheath	Sheath material dependent
Dielectric Spectroscopy (DS) **OR** Dielectric Dissipation Factor (DDF) & Capacitance	Moisture content of main insulation	Test voltage level, cable age and insulation material type dependent
Partial Discharge (PD)	PD activity within insulation components	Test voltage level, cable age, magnitude and phase resolved position dependent
High Voltage (HV) Withstand	Voltage withstand capability of insulation components	No breakdown of insulation

There was considerable discussion around the HV withstand test level and duration that the cables should be exposed to, wanting to assess the cable's condition while not damaging the asset. The conclusion was that the test voltage levels and acceptance criteria shall be the same as for commission testing as laid down in SMI 12-01-02.

To date the following statistics are recorded

- One cable has experienced an explosive failure during the HV withstand test
    - Prior to the failure, no excessive levels of PD activity were recorded
- Approximately 60% of cable circuits tested have displayed unacceptable measurements
    - None of these failures have been explosive in nature
    - The vast majority of these 'failures' have been within terminations and/or joints, where excessive levels of PD have been measured
    - There have been some failures due to moisture contamination (water treeing) within the cable

4.10 REFCL GFN

The REFCL GFN is required to be compliance tested on an annual basis

The tests shall consist of

- Insulation Tests used to identify any residual weaknesses in the network that would likely arise during the operation of a REFCL by testing phase by phase with an increased voltage being pushed through the lines for at least 3 minutes
- Primary Earth Faults as prescribed by the ESV as part of the bushfire mitigation plans to ensure the REFCL operates as per the regulations by simulating fault currents. This testing is a regulatory requirement.

5 Risk management

The risks associated with delivery of the program of primary asset replacement are shown in the table below.

Risk	What could occur	Actions & controls
Interference / clashes with other project(s) and project scope creep.	Delivery delays leading to non-compliance with Bushfire Mitigation Regulations and the approved Bushfire Mitigation Plan. Down time for construction crews	Continual engagement with Network Planning Teams and delivery partners. Network Programs constant review of Portfolio projects. Dedicated Program Sponsor Team established.
Delivery delays and the time primary assets are not available resulting in not meeting REFCL regulatory obligation.	Delivery delays leading to non-compliance with Bushfire Mitigation Regulations and the approved Bushfire Mitigation Plan.	Monthly reporting of the progress of the project from delivery partners through to the Program Team / Steering Committee and Energy Safe Victoria. Regular updates of Asset Management System enabling progress to be tracked real-time. Well planned schedule of works. Early engagement with Control Energy Operations Team (CEOT), delivery partners and field personnel to ensure resourcing availability.
Extent of customer supply interruption becomes unacceptable and causes delay to program delivery.	Customer/community communications/ engagement.	

5.1 Procurement

Some primary assets that will require replacement are standard stock items. Others are on long lead times or require extended outages to realise installation. These items need to be identified at an early stage of the investigation to ensure supply reliability and availability is maintained.

These shall be procured utilising AusNet Services' standard procurement and governance processes which include competitive tendering to ensure the cost per unit is efficient.

5.2 Program Governance

While the primary asset replacement program will be managed using the AusNet Services' Portfolio Framework, an overarching REFCL Program Governance Framework has been established in order to provide end-to-end Program oversight and accountability, to identify and manage program level risks.

The REFCL Program Governance Framework aligns to AusNet Services' values and commitment to mission zero with:

- Clear accountabilities, reporting and robust risk and issue management;
- Sustainable, long term, reliable, economical and workable whole of life designs;
- Delivery as per agreed time frames without compromising reliability and other service standards;
- Integration where possible with the rest of the AusNet Services work program;
- Compliance with required obligations;
- Strong relationships with all stakeholders in order to successfully manage change;
- Development of internal capability in order to facilitate the transition to business as usual; and
- Use of business as usual processes and resources where possible.

6 Concluding Comments

This document has explained that:

- The proposed scope of primary asset replacements is the lowest cost and highest community benefit option for addressing the specific issues on REFCL protected networks
- A standard approach to estimating the costs of primary asset replacements has been used
- The key assumptions underpinning our forecasts are reasonable;
- We have identified the key risks in relation to primary asset replacements and taken appropriate risk mitigation measures
- Our projected costs (refer to relevant Planning reports) are consistent with the estimated average unit costs in the RIS

In addition, it should be noted that our forecast expenditure for primary asset replacement has been subject to our standard business case review and approval processes. This work will also be subject to our project management and governance arrangements.

For these reasons, we regard the forecast expenditure for primary asset replacement as prudent and efficient, in accordance with the Rules & requirements relating to contingent projects.