REFCL Functional Performance Review

Report for Energy Safe Victoria

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Executive Summary

Two Victorian Electricity distributors, AusNet Services and Powercor (the distributors[1]) have deployed Rapid Earth Fault Current Limiter (REFCL) technology in accordance with the 2016 amendment to the Electricity Safety (Bushfire Mitigation) Regulations 2013 (the Regulations). The purpose of the Regulations is to reduce the risk of bushfire starts caused by electrical assets, following the devastating Victorian bushfires in 2009.

This report has been prepared for Energy Safe Victoria (ESV) in response to a recommendation from the Grimes Report[2] that an interim assessment of the REFCL program should be undertaken.

Our overall assessment is that the operational performance of the installed REFCLs is meeting expectations in relation to bushfire risk mitigation. In some instances, the installed REFCLs have exceeded these expectations by responding to more complex faults and reducing bushfire risk. Each distributor has identified specific cases where a fire start is likely to have been prevented as a result of REFCL operation. Evidently, these are positive outcomes for the community. The distributors have also highlighted the additional safety benefits of REFCL technology in reducing the risk of electrocution.

The REFCL program has raised a number of challenges for the distributors, principally because the deployment of the technology for bushfire risk reduction was a ground-breaking initiative that relied on a single supplier to deliver the REFCL technology capable of meeting the performance standard specified in the Regulations. In addition, the deployment of the technology at each of the specified zone substations raised location-specific challenges in meeting the compliance standard. The required conversion from solid earthing to resonant earthing also created new challenges and training needs for operational staff. The distributors have committed significant resources and management effort to overcome these challenges.

It is evident that the anticipated network reliability improvements from REFCL deployment have not yet materialised. In broad terms, the rapid operation of REFCL technology in tripping a faulted feeder results in more customers being off supply, as traditional protection devices do not operate as quickly (or at the same sensitivity) as REFCLs. The incompatibility of existing fault detection equipment with REFCL operation and the likely reduction in visible (and easily detectable) damage at the fault location leads to poorer reliability outcomes. Material improvements in reliability performance depend on further development of technology to locate high impedance earth faults.

In accordance with the Grimes recommendation 27, we have also examined the risks and uncertainties in relation to the remaining tranches of the REFCL program and considered whether these warrant a change in either the performance standard or project timing. It is evident from our enquiries that the distributors have identified and are actively managing the risks and uncertainties that may adversely affect the delivery of the REFCL program. Moreover, in addressing recommendation 27, we do not believe that a change to the Regulations or the timing of the program would assist in further mitigating these risks, particularly as the distributors have already embarked on the final tranche of the program.

1 Jemena is also required to comply with the Regulations at one zone substation, but not until 1 May 2023. United Energy has also installed REFCLs, but is not required to do so by the Regulations.

2 Independent Review of Victoria's Electricity and Gas Network Safety Framework, December 2017, recommendation 27.

Findings and recommendations

This section summarises our findings and recommendations presented under the three elements of our scope of work.

REFCL technology performance

Findings:

1. Tranche 1 of the REFCL program has been commissioned in accordance with the timeframes envisaged in the Regulations, with the exception of AusNet Services' zone substations at Woori Yallock and Kinglake, where time extensions have been granted by ESV to 1 November 2020 and 29 April 2021 respectively.

2. The operational fault data and compliance testing results indicate that the REFCLs are operating in accordance with the Regulations. In addition, each distributor has identified specific cases where REFCL operations are believed to have prevented fire starts. This finding should provide comfort to the community and other stakeholders that the installed REFCL technology is capable of preventing bushfires.

3. The analysis of fault information provided by the distributors indicates that the REFCLs deployed to date are effective in responding to phase-to-earth faults, and therefore reducing fire risk. However, given the limited operational data, it is not possible to conclude categorically that the fire risk reduction estimates in the Regulatory Impact Statement that underpin the Regulations are being achieved. While we cannot make a positive finding in relation to this issue, there is no evidence to indicate that the REFCLs are failing to achieve the intent of the Regulations in relation to fire risk reduction.

4. The distributors have adopted appropriate testing procedures. For anomalous results with unknown root causes (Type B), the distributors adopt different actions to demonstrate compliance. While each approach is considered reasonable, there is an opportunity to align the distributors' actions to ensure that a consistent approach is adopted, which avoids any risk of ambiguity as to whether compliance has been demonstrated. Similarly, it is desirable for ESV's acceptance regime in relation to anomalous results to be aligned with the distributors' testing procedures.

5. ESV has adopted an appropriately pragmatic approach to assessing compliance by providing conditional acceptance in circumstances where a distributor is able to demonstrate that all steps, as far as practicable, have been taken to achieve compliance. Given the newness and complexity of implementing REFCL technology to mitigate bushfire risk, we consider ESV's approach to be appropriate. It is noted that as industry experience continues to develop and technical challenges are resolved, conditional acceptance may not be necessary in future. The current arrangements could be enhanced by ESV providing the distributors with details of its acceptance regime. By issuing its acceptance regime, ESV will eliminate any remaining uncertainty regarding its approach to assessing compliance and its future approach to conditional acceptance.

6. In seeking a time extension in relation to Woori Yallock and Kinglake, AusNet Services explained the technical issues (harmonics and erroneous delta admittance calculations) and its proposed remedial steps. Our finding is that AusNet Services and ESV have acted reasonably in seeking and granting time extensions. To assist those electricity customers and stakeholders that would like to understand the

current status of the REFCL program, including decisions to grant time extensions, ESV should consider providing summary information on its website in a customer-friendly format.

7. There are opportunities to improve REFCL performance. For example, both distributors have experienced restriking faults on their REFCL protected network, which have led to REFCL mal-operations. As these faults typically occur on cabled sections of the network, they are more likely to cause nuisance tripping rather than pose a significant fire risk. From experience to date, REFCLs have not been effective in treating restriking faults due to the current design of the REFCL. We understand that distributors are working to improve REFCL performance in relation to restriking faults.

8. The newness of REFCL technology and the limited amount of fault data indicate that information sharing across the sector is essential to maximise the opportunity to deliver future improvements in REFCL performance. The annual analysis of fault data, supported by a common database, would promote longer term improvements in REFCL development and operation.

9. Insulation testing is undertaken to ensure that network assets are able to withstand REFCL operation. To date, it is evident that AusNet Services and Powercor have adopted different approaches to insulation testing. The key difference is that Powercor adopted a longer testing duration than AusNet Services, although we note that AusNet Services has recently increased its testing duration. In our view, there is an opportunity for AusNet Services and Powercor to work together to determine whether a common methodology should be adopted.

10. The distributors have taken appropriate steps to manage the costs of delivering the REFCL program efficiently, supported by a regulatory and compliance framework that requires the mandated standards to be achieved by specified dates. The required works include:

    - Zone substation augmentation;
    - REFCL sizing;
    - Asset hardening and replacement;
    - Treatment of HV customers;
    - Network capacitive balancing activities; and
    - REFCL system testing.

    In relation to each category of work, we consider that the distributors have adopted prudent and efficient solutions to the above issues. In relation to insulation stress testing, there may be an opportunity to align the methodologies adopted. This is a matter for ESV and the distributors to consider, but it does not affect the efficiency or prudency of the work undertaken to date.

Recommendations:

A. ESV should provide its acceptance criteria to the distributors. ESV should ensure its approach to anomalous test results is reflected in the distributors' testing policies to ensure a consistent approach to resolving issues.

B. Fault information should be analysed by each distributor annually after each summer period to assess REFCL performance. Ideally, this analysis should be captured in a common database designed by the distributors to enable data sharing. Fault reports should contain information such as local weather conditions, fault type categorisation, fault impedance, photos, REFCL operating mode and detection thresholds, network configuration, any abnormal behaviour or sequence of events, fault impedance and a cross check of actual waveform data against REFCL commissioning and regulatory benchmarks. In addition to regularly assessing REFCL performance, this information and accompanying analysis should assist in identifying opportunities to optimise REFCL operation to deliver better community outcomes in terms of bushfire risk reduction, reliability performance and costs. Fault reports produced by the distributors should not only validate that the REFCL device has operated as intended, but also comment on the likelihood that REFCL operation has avoided a fire. These reports should be provided annually to ESV in June.

Emerging issues affecting program delivery

Findings:

11. The distributors have effective internal processes for identifying and managing risks to the REFCL program, including risks that are only partly within their control.

12. Both distributors have implemented effective risk mitigation measures in relation to sole supplier risk. These measures include working with Swedish Neutral to resolve issues and exploring alternative REFCL products with other suppliers. Our view is that sole supplier risk does not warrant any adjustment to the REFCL performance standard or the program timing.

13. A number of technology reliability issues have emerged through the practical experience of implementing the REFCL technology on the distributors' actual networks, which are more complex and larger compared to the REFCL trials. The technical issues include:

    - RCC drift and Slow RCC;
    - Inverter Calibration;
    - Inverter tripping;
    - Harmonics; and
    - Admittance calculations.

    While the experience and response of each distributor has differed, both companies have worked collaboratively with one another and with Swedish Neutral to resolve these technical issues. For example the treatment of Harmonics was initially approached differently by the distributors however a more consistent approach is likely to be applied going forward. Given the advanced nature of the program, the availability of time extension provisions, and the success already achieved in delivering the REFCL program, there is no case for delaying the completion of the REFCL program to address outstanding technical issues.

14. The distributors have been proactive in initiating programs to replace or upgrade systems or equipment they have identified as incompatible with the REFCL protected networks. For example, the distributors'

ACR program has efficiently managed the risk of mal-operation. Our review indicates that no change is required to the REFCL program or the technical requirements in order to address the risks associated with incompatible equipment. There are, however, outstanding issues that continue to be addressed particularly in relation to the adverse reliability consequences associated with REFCL deployment.

15. Our assessment is that the distributors have committed significant resources to the effective management of the REFCL program. These efforts have included change management initiatives to assist internal engineering and operational staff. Furthermore, external stakeholders such as HV customers have been continuously supported throughout the REFCL program.

16. Distributors have an on-going training need in order to maximise the customer benefits from the REFCL program. In particular, further training and supporting infrastructure investment will be required to improve fault identification and analysis, especially as more REFCLs are installed. Improved outcomes for customers over time will depend on better fault data capture by first responders in the control room and fault crews. Better data capture is essential in order for distributors and ESV to analyse REFCL performance and optimise future operation.

17. Given the complex nature of the REFCL, there are a number of failure mechanisms that could influence earth fault protection detection levels. Strategic spares should be held to enable failures to be addressed as quickly as possible. However, a REFCL's short-term performance should be maintained as far as practicable, even if some assets fail. For example, if the controller of the REFCL fails, then the zone substation and feeder protection schemes should be able to operate for a resonant earthed network without the power electronics i.e. Arc Suppression Coil only. In this instance, the fault current will not be reduced to Required Capacity levels, although fire risk will still be lower than would occur with traditional earthing at the zone substation. The distributors are currently exploring ways to better integrate the REFCL in such cases through the use of protection functions in feeder protection relays.

18. In relation to stakeholder engagement, it is important that customers and other interested parties understand the overall progress of the REFCL program, including the current status of the program in terms of compliance and time extensions. By making this information publicly available, all stakeholders will have a better understanding of the technical challenges involved and the efforts by the relevant parties to resolve them. In our view, the provision of high-level, customer-friendly information that succinctly captures the current status of the program will assist in building community confidence in the REFCL program.

19. Network damping affects the capability of the REFCL device to detect high impedance faults in accordance with the Regulations. Currently, there is no method to pre-emptively obtain accurate damping values through modelling or calculations. The risk to the distributors is that the true damping value is not known until it is measured by the REFCL, which creates a compliance risk. This risk would be mitigated if improved methods were developed to better predict damping values before REFCLs are installed.

20. The Regulations state that the faulted phase voltage collapse should be assessed at the zone substation busbar, which is appropriate when assessing compliance. However, our consultation with REFCL suppliers suggests that refocusing effort on the energy released at the fault site may lead to further improvements in bushfire risk reduction.

21. A number of challenges will arise in terms of maintaining compliance, particularly as the network grows and network configurations change. However, these challenges do not support a change in the REFCL implementation timetable or the definition of Required Capacity. The current regulatory framework has flexibility through the technical exemption regime and through the Bushfire Mitigation Plan to ensure that achieving on-going REFCL compliance appropriately balances the interests of customers in terms of bushfire risk mitigation, reliability performance and cost. In our view, the framework should be kept under review to ensure that discretion is being exercised appropriately by ESV and the distributors to deliver the best outcome for the community.

Recommendations:

C. It is recommended that distributors ensure that they hold sufficient strategic spares to ensure that REFCLs can be returned to service in the event of a component failure. In addition, distributors should ensure that the impact on REFCL performance as a result of a component failure is minimised. In this regard, the distributors should continue to explore ways to better integrate the REFCL and provide back-up protection which utilises the Arc Suppression Coil in the event that the REFCL controller fails.

D. It is recommended that ESV provides better information on its website in relation to the overall progress of the REFCL program, including the current status of the program in terms of compliance and time extensions. The information should provide a high-level summary in a customer-friendly format.

E. It is recommended that the distributors explore methods to better predict damping values accurately, and remove the reliance on the bounded range currently adopted to mitigate the risk to the program and to maintaining compliance.

F. It is recommended that the distributors continue to collaborate with REFCL suppliers to develop fast voltage reduction and reduced energy released at the fault site with the objective of further reducing bushfire risk. The distributors are required to demonstrate their REFCL device can be operated at Required Capacity however if the REFCL can be configured and operated differently to deliver an improved risk reduction at the fault site then this should be explored.

Unexpected benefits and future opportunities

Findings:

22. In terms of unexpected benefits, the REFCL program has led to improvements in earth fault treatment and the ability to reduce fire risk for complex faults if the sequence of events result in sufficient network dissymmetry to trigger REFCL operation.

23. In relation to opportunities to obtain future benefits, a key area of focus is likely to be network reliability, which has been adversely affected by the REFCL implementation program. The principal impediment to achieving reliability improvements relates to product development and the duration of REFCL operation for a fault condition. We anticipate that the distributors will make progress in resolving these challenges once the implementation of the REFCL program has been completed.

24. The REFCL has the ability to manually control phase-to-ground voltages on polyphase networks and can be used to facilitate HV testing activities such as partial discharge testing. This function has been widely used in Europe to detect incipient dielectric collapse with HV equipment. Additionally, in some cases where

partial discharge is present the REFCL has been configured to adjust phase-to-ground voltages deferring asset failure and allowing critical assets to remain online until the asset is repaired or replaced.

25. The distributors have highlighted the additional safety benefits of REFCL technology in reducing the risk of electrocution for workers and the general public. Powercor and United Energy have implemented protection and control schemes to maintain REFCL protection while live line works are being conducted on REFCL protected networks. This is a potential area where a uniform approach should be adopted to ensure safety benefits across all REFCL installations are maximised.

26. Treatment of faults such as cable restriking is a potential benefit of REFCL technology that is yet to be realised. Although statistics to date indicate a low rate of occurrence, it is expected that cable quality and installation conditions may deteriorate more rapidly on REFCL protected networks, potentially increasing the rate of occurrence. There is an opportunity to further improve the inverter control and algorithms to manage these types of faults reliably.

27. Given the newness of REFCL technology, it is likely that the distributors will continue to find opportunities to maximise the benefit to customers in terms of bushfire risk reduction, reliability and costs. At this stage, there is no reason to suppose that the achievement of these benefits requires a change to the existing Regulations.

Recommendations:

G. It is recommended that the distributors continue to explore fault locating technologies, including fault finding tools, to assist in improving network reliability impacts from sustained outages.

H. We recommend that the distributors review and align their approach to maximise the benefits from reduced electrocution and the integration with live line sequence on REFCL protected networks.

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1. Background and introduction

1.1. Development of the current Regulations

Following the Black Saturday bushfires in 2009, the Victorian Bushfire Royal Commission made several recommendations with respect to fires initiated from distribution electricity networks. An expert Powerline Bushfire Safety Taskforce was subsequently established to consider how the Victorian Government should implement the recommendations related to powerline replacement (recommendation 27) and changing the network reclose function (recommendation 32).

The Taskforce's report indicated that the optimal means of reducing bushfire risk from SWER and 22kV powerlines was a mixture of powerline replacement, automatic circuit reclosers (ACRs) on SWER lines and the selective installation of REFCLs. The Taskforce also identified the need for further research and development, particularly as REFCLs had not been used for bushfire suppression previously.

In December 2011, the Government accepted the Taskforce's recommendations, and established the Powerline Bushfire Safety Program (PBSP) to determine the optimal method for deploying REFCLs for bushfire prevention. The research programs ultimately quantified a performance standard that could meet an acceptable bushfire risk reduction of 90% from phase-to-ground faults on 22kV powerlines. The REFCL performance standard specified fault detection, fault response and fault management capacities that must be achieved in the event of a phase-to-ground fault on a polyphase electric line in order to reduce fire ignition risk to a low level.

Following the conclusion of the powerline ignition research program, the Government amended the Electricity Safety (Bushfire Mitigation) Regulations 2013 (the Regulations) in 2016 to incorporate the REFCL performance standard and subsequently defined it as 'Required Capacity', which is set out below:

REFCL Required Capacity

a) Reduce the voltage on the faulted conductor in relation to the station earth when measured at the corresponding zone substation for high impedance faults to 250 volts within 2 seconds; and

b) Reduce the voltage on the faulted conductor in relation to the station earth when measured at the corresponding zone substation for low impedance faults to —

   (i) 1,900 volts within 85 milliseconds; and

   (ii) 750 volts within 500 milliseconds; and

   (iii) 250 volts within 2 seconds; and

c) During diagnostic tests for high impedance faults, limit —

   (i) fault current to 0.5 amps or less; and

   (ii) the thermal energy on the electric line to a maximum i^2t value of 0.1.

Additionally, the Regulations nominated 45 zone substations where the Required Capacity must be met. Of these 45 zone substations, 22 are located in each of AusNet Services' and Powercor's network distribution areas, with the remaining zone substation in Jemena's network. The Regulations specify the timeframes by which the selected zone substations must meet these requirements.

A points system is applied to each zone substation, reflecting the relative importance of achieving the Required Capacity at each zone substation in terms of bushfire risk mitigation. The Regulations require a minimum number of points to be achieved by 1 May 2019 and 1 May 2021, with all 45 zone substations required to have the Required Capacity by 1 May 2023. In effect, therefore the REFCL implementation program is to be completed in three tranches.

It is important to note that extensive research and testing, carried out over several years, underpinned the technical specifications in the Regulations. In particular, the Regulations reflect a quantitative assessment of the electrical behaviour likely to avoid the ignition of dry vegetation in close proximity to a powerline earth fault. This quantification was based on tests in 2011, 2013, 2014 and 2015. Further comprehensive testing was also undertaken at a custom-built test facility adjacent to AusNet Services' Kilmore South zone substation during 2015 to ensure that the proposed performance standard was appropriate, given the objective of bushfire risk reduction and the capability of available REFCL technology.

1.2. Review of energy safety framework

In December 2017, Dr Paul Grimes completed a review of the safety frameworks applying to electricity and gas networks in Victoria, which are administered by ESV[3]. The review noted that a major focus for the Victorian electricity network safety framework in recent years has been the implementation of measures in response to the recommendations of the Victorian Bushfire Royal Commission. As already noted, the resulting actions included investments in research and development, infrastructure replacement programs, and the introduction of new regulations.

The Grimes Review emphasised the importance of a careful approach to implementation so that program settings can be adjusted in a measured fashion when justified. Given the broader public interest and policy implications, it recommended that annual implementation reports be provided to the Minister for Energy, Environment and Climate Change. The Grimes Review commented that the reports should provide information on the costs and risk reduction benefits of the program in light of practical implementation experience, and an assessment of emerging issues that may require adjustments to program timing or technical requirements. For example, the Grimes review mentioned the use of exemptions from meeting the compliance requirements on certain feeders, where risks can be more cost effectively met through alternative mechanisms other than REFCLs[4].

In response to the Grimes Review's recommendation for an annual implementation report, ESV has engaged PSC Australia Pty Ltd to undertake a review of the technical performance of REFCLs based on operational experience to date. A separate consultancy is being undertaken by The Nous Group to consider the costs and benefits of the REFCL program. It is noted that these reports are the first to be prepared in response to the

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3 Independent Review of Victoria's Electricity and Gas Network Safety Framework, December 2017.

4 Ibid, page 24.

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Grimes Review recommendation, as insufficient operational experience in relation REFCL performance was available to warrant a report in prior years.

1.3. Our scope of work and structure of this report

Our scope of work has three components, which are set out below:

1. Determine whether the REFCL technology performance as deployed is achieving the Required Capacity at the prescribed substations, as defined in regulation five of the Electricity Safety (Bushfire Mitigation) Regulations 2013, and whether this efficiently meets the intent of the Regulations as documented in the Regulatory Impact Statement (RIS).

2. Advise on any current, emerging or unforeseen issues that may cause the program timing or technical requirements to be adjusted.

3. Advise on any unexpected benefits (and future opportunities) that have arisen following the deployment of REFCLs e.g. the detection of fault types that were not anticipated and public safety (e.g. reduction in electrocution risk).

This report is structured in accordance with the three elements of our scope.

2. REFCL technology performance

This section addresses the first element of our scope of work, which is to consider whether REFCLs have been deployed in accordance with the Regulations and are delivering the expected reductions in bushfire risk. To address this issue, this section considers the following questions in relation to REFCL deployment and performance:

- Were the distributors successful in deploying REFCLs to achieve the Required Capacity within the required timeframes?
- Have the distributors adopted appropriate testing procedures and policies?
- Are ESV's acceptance criteria appropriate in assessing the distributors' compliance with the Regulations?
- What does the actual fault data reveal about REFCL performance?
- Based on the available evidence, is the intent of the Regulations being met?
- What observations, if any, can be made regarding the efficiency of REFCL deployment?

Each of these questions is addressed in turn. Each section concludes with a clear statement of our findings and recommendations (if any).

2.1. Deployment of REFCL Technology

In 2016, AusNet Services and Powercor commenced a major installation program to comply with the requirements of the amended Electricity Safety (Bushfire Mitigation) Regulations 2013. The installation program will be delivered in three tranches to achieve a sufficient number of compliance points as Required Capacity is achieved at the zone substations prescribed in Schedule two of the Regulations. The delivery of the minimum required compliance points and target dates for AusNet Services and Powercor are outlined below:

- Tranche one - Achieve a minimum of 30 points before the 1 May 2019;
- Tranche two - Achieve a minimum of 55 points before the 1 May 2021; and
- Tranche three - Achieve the balance of points before 1 May 2023.

The installation program initiated by each distributor is inclusive of all works required to demonstrate that each element of Required Capacity is met or exceeded, while also ensuring that network safety, network reliability, personal safety, and compliance with various regulations, codes, standards and guides, are not compromised. The works extend beyond the zone substation to include network balancing, asset hardening, asset replacements and engagement with all HV customers affected by the Regulations.

AusNet Services, Powercor and Jemena are the Victorian electricity distribution businesses that have nominated zone substations in the Regulations that require installation of REFCL equipment. Jemena's installation is not required until Tranche three. To date, deployment and associated works to implement REFCL technology to Required Capacity has predominantly been undertaken by AusNet Services and Powercor (the distributors). United Energy has also installed three REFCLs, which are not mandated by the Regulations.

AusNet Services has achieved 23 points in Tranche one of its installation program, which consists of eight zone substations and a maximum total of 32 points. To date, of the eight Tranche 1 REFCL installations, six have been deemed compliant by ESV, while the two remaining stations at Woori Yallock and Kinglake have been granted a time extension. These two zone substations are REFCL protected, but the Required Capacity has not been demonstrated fully.

The time extension means that the deadline for these stations has been deferred to allow for remedial works to overcome technical issues and demonstrate full compliance. Compliance must be demonstrated at Woori Yallock no later than 1 November 2020 for five points, and compliance must be demonstrated at Kinglake no later than the 29 April 2021 to gain a further four points. Failure to achieve compliance at either of these zone substations may result in financial penalties.

As a result, while AusNet Services currently has 23 points against a minimum requirement of 30, successful completion of the remaining two zone substations will achieve the required points total for Tranche one. AusNet Services has demonstrated compliance at two Tranche 2 zone substations, totalling three compliance points. To date, AusNet Services has therefore achieved 26 compliance points. The table below summarises AusNet Services' current program status as at 11th September 2020.

Table 1: AusNet Services' REFCL program status

Tranche 1		Tranche 2		Tranche 3	
Zone Substation	**Points**	**Zone Substation**	**Points**	**Zone Substation**	**Points**
Myrtleford	3	Wonthaggi	1	Lang Lang	1
Barnawartha	3	Mansfield	2	Sale	1
Kilmore South	3	Ringwood North	2	Benalla	2
Rubicon A	4	Eltham	2	Kalkallo	3
Kinglake[5]	4	Wodonga TS	3	Ferntree Gully	2
Wangaratta	5	Moe	3		
Seymour	5	Belgrave	3		
Woori Yallock[5]	5	Lilydale	3		
		Bairnsdale	4		
Total Attainable Points	32		23		9
Minimum Points Required (cumulative)	30		55		64
Points Achieved by Tranche	23		3[6]		0

5 Zone substations are subject to a time extension.

6 AusNet Services has also demonstrated Required Capacity at Wonthaggi and Mansfield zone substations.

Powercor has achieved 30 points in Tranche one of its installation program, which consists of seven zone substations deemed compliant by ESV. In addition, Powercor has demonstrated compliance at three Tranche 2 zone substations, totalling eight compliance points. To date, Powercor has therefore achieved 38 compliance points. The table below summarises Powercor's current program status as at 11th September 2020.

Table 2: Powercor's REFCL program status

Tranche 1		Tranche 2		Tranche 3	
Zone Substation	**Points**	**Zone Substation**	**Points**	**Zone Substation**	**Points**
Gisborne	3	Ararat	1	Corio[7]	1
Camperdown	4	Ballarat North	4	Geelong[7]	4
Castlemaine	4	Ballarat South	5	Hamilton	2
Eaglehawk	5	Bendigo	1	Koroit	2
Maryborough	5	Bendigo TS	5	Merbein	1
Winchelsea	5	Charlton	2	Stawell	1
Woodend	4	Colac	5	Waurn Ponds	4
		Terang	2		
Total Points	30		25		15
Minimum Points Required (cumulative)	30		55		70
Point Achieved by Tranche	30		8[8]		0

While AusNet Services and Powercor have encountered significant challenges in deploying REFCL technology, which are discussed in further detail in this report, the REFCL program has been deployed in accordance with the timeframes envisaged in the Regulations. Although time extensions to demonstrate Required Capacity have been granted for AusNet Services' zone substations at Woori Yallock and Kinglake, the REFCLs have been deployed and are operational.

2.2. Distributor's testing procedures and policies

To demonstrate that Required Capacity can be achieved at each zone substation, the distributors have documented their testing procedures and policies. Each distributor summarises these policies and procedures in their Bushfire Mitigation Plan (BMP), which is accepted by ESV, and provides cross-references to other relevant internal policy documents.

AusNet Services and Powercor have established very similar testing procedures to determine whether Required Capacity has been achieved, as outlined in the table below. These procedures involve constant coordination with teams located at the zone substation; a centralised control room; and a remote test site that aims to replicate a phase to ground fault.

7 Zone substations have been excluded from the program on the condition a new complying zone substation is built that supplies agreed service areas of the existing polyphase distribution network originating from these zone substations.

8 To date, Powercor has also demonstrated Required Capacity at Ararat, Charlton and Colac zone substations

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Table 3: Testing procedures

No.	Procedure	Adopted by PAL	Adopted by AST
1	Execute the required sequence to close the HV Test Resistor Automatic Circuit Recloser (ACR) and apply a 25,400 ohm or 400 ohm impedance earth fault.	YES	YES
2	Observe compensation by the REFCL system	YES	YES
3	Wait a minimum of three (3) seconds to ensure sufficient data capture for the two (2) second milestone within the Part A performance clause	YES	YES
4	Initiate a confirmation test	YES	YES
5	Observe action and completion of the confirmation test	YES	YES
6	Confirm the HV Test Resistor ACR has opened	YES	YES

The performance criteria defining Required Capacity is separated into Parts A, B and C, which are demonstrated by two types of tests. One test (Type I), aims to demonstrate Parts A and C have been satisfied, while another test (Type II) addresses the requirements of Part B. An outline of each test is detailed in the table below.

Table 4: Type I and Type II tests

No.	Test Type	Adopted by PAL	Adopted by AST
1	Type I Test Part A – High Impedance Earth fault sensitivity on a REFCL protected network to reduce the voltage on the faulted conductor in relation to the station earth when measured at the corresponding zone substation for high impedance faults to 250 volts within 2 seconds Part C – Management of High Impedance faults on a REFCL protected network during diagnostic tests, to limit— i. fault current to 0.5 amps or less; and ii. the thermal energy on the electric line to a maximum i^2t value of 0.10	YES	YES
2	Type II Test Part B – Response to Low Impedance earth faults on a REFCL protected network that reduce the voltage on the faulted conductor in relation to the station earth when measured at the corresponding zone substation to— i. 1900 volts within 85 milliseconds; and ii. 750 volts within 500 milliseconds; and iii. 250 volts within 2 seconds	YES	YES

To foster and maintain confidence in the reliability of the compliance test results and the performance of the REFCL system, both distributors undertake successive tests for both Type I and Type II tests, as outlined in the table below.

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Table 5: Successive Type I and Type II tests

No.	Test Type	Adopted by PAL	Adopted by AST
1	Type I Test Three (3) successive compliant tests per phase resulting in six (6) tests per feeder representing the requirements for Parts A and C	YES	YES
2	Type II Test Three (3) successive compliant tests per phase resulting in six (6) tests per feeder representing the requirements for Part B	YES	YES

Recording of Type test results have been further split into compliance test targets by the distributors to ensure that all parameters of Required Capacity can be quantified and to meet or exceed the 90%[9] fire risk reduction objectives of the performance standard. As can be seen in the following table, achievement of four targets in total from a single Type I High Impedance test is required to demonstrate compliance with Part A and C of Required Capacity. A total of four targets is required from a single Type II Low Impedance test to demonstrate compliance with Parts B of Required Capacity[10].

Table 6: Test targets

Target	i	ii	iii	iv	Total
Part A	Detection of a high impedance fault	Reduce to <250V within 2 seconds			2
Part B	Detection of a low impedance fault	1900 volts within 85 milliseconds	750 volts within 500ms	250 volts within 2s	4
Part C	Limit diagnostic current to 0.5A or less	Limit thermal energy to $0.1A^2s$			2

Collectively, achieving eight targets indicate that initial compliance has been demonstrated on a particular phase of the feeder to which the fault has been applied. Given each type test is to be completed three times (3) in succession and on each phase (3) of the polyphase electric line, a total of 72 targets are required for each feeder originating from the zone substation in order to be deemed compliant.

During testing, both distributors experienced results that were unexpected and not aligned with the current knowledge and operational experience of the REFCL devices. These anomalous results have been categorised

9 ACIL Allen, Regulatory Impact Statement, Bushfire Mitigation Regulations Amendment, November 2015, figure 6, page 46.

10 The distributors differ slightly in the assessment of test targets for Part B compliance, as Powercor currently use 3 targets where the 'Detection of a low impedance fault' target is not counted. The rationale behind this approach is that the remaining targets would not be satisfied without the detection of the low impedance fault.

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as Type A or Type B, as shown in the table below. Where the anomalous result does not have a known root cause (Type B), it is subject to further actions specified by the distributor to demonstrate compliance.

Table 7: Anomalous test results

No.	Anomalous Result Type	Adopted by PAL	Adopted by AST
1	Anomalous Type A The cause is understood and remedied; or can be ignored in future tests.	YES	YES
2	Anomalous Type B The root cause is not found, not established or cannot be remedied with a high level of confidence	YES	YES

While both distributors adopt the same classification approach, they adopt different actions to demonstrate compliance in relation to Type B anomalous results, as follows:

- Powercor:[11]

  "Increase the number of successive compliant tests from two (2) to five (5) for the nominated test in which the anomalous result occurred……The level of confidence obtained shall be no less than 90%, when comparing the number of Group B anomalous results against the total number of successful tests."[12]

- AusNet Services:

  "The same test will not be consecutively repeated more than five (5) times. The average of the 5 results will be compared against the standard definition to determine the result of the test. A rate of occurrence of one in ten tests [for Anomalous Type B results] will be considered a pass."[13]

Currently, the distributors differ in their approach to annual compliance testing of zone substations that have previously been accepted by ESV as compliant. Powercor adopts an annual test assessment process to determine the type and number of tests to be completed. Key network metrics such as damping, dissymmetry and line impedance are considered together with REFCL operational experience in the year leading up to annual compliance testing. ESV has accepted Powercor's annual compliance testing policy this year given the substantial volume of testing that has been completed. It is understood that AusNet Services plans to adopt a similar approach with their annual compliance testing policy. It is anticipated their policy will be accepted by ESV on the basis that comparable levels of testing and REFCL operational experience to Powercor is achieved.

In our view, the testing procedures adopted by AusNet Services and Powercor are appropriate. In reaching this finding, we note that the distributors' procedures are consistent with those adopted in the REFCL trials and the

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11 CP_PAL_REFCL_103, Demonstration of Required Capacity, page 8

12 Stephenson, B., Demonstration of Required Capacity, revision 1.0, 2017, page 8

13 Scott, D., Demonstration of Required Capacity, revision 3.0, 2019, page 7

recommendations of the REFCL compliance testing activity discussion paper.[14] We note that there is an opportunity to align the distributors' target assessment of Part B compliance (where there is a minor difference) and actions to address anomalous Type B test results to ensure consistent test measures to determine compliance. In our view, ESV should seek to align these testing procedures.

2.3. ESV's acceptance criteria

ESV's approach to determining whether the Required Capacity has been achieved at each nominated zone substation is explained in two internal ESV documents:

- REFCL Compliance Testing Observations Procedure; and
- REFCL Compliance Testing Strategy.

ESV staff employ these documents when observing and assessing initial compliance and annual validation test results. The documents play a key role in deciding whether a nominated zone substation has achieved Required Capacity, and whether technical issues that prevent unconditional acceptance warrant civil penalties being applied.

The ESV REFCL Compliance Testing Observation Procedure document details information that must be measured, recorded and provided to ESV before and after compliance testing. It describes the information that will be observed by ESV representatives during initial compliance and annual testing. It also details the assessment criteria for each distributor's testing plan and how the test results should be categorised.

The ESV REFCL Compliance Testing Strategy is intended to provide guidance on ESV work procedures and acceptance criteria in order to achieve compliance with the Regulations. In doing so, it summarises the current state of knowledge and theory regarding REFCL deployment, drawing from extensive research, testing and operational experience of personnel in the Victorian electricity industry. In addition, it provides a detailed record of how anomalous test results have been resolved. We note that this information is a potentially useful resource for ESV and the distributors in completing future tranches of the REFCL installation program.

The REFCL Compliance Testing strategy recognises that ESV is required to administer the Regulations and conduct their compliance assessment in accordance with the Regulations. In particular, section 9.1 states that "ESV must administer the Regulations within the bounds of the law". In addition, Section 9.2 states that ESV's representatives will be responsible for assessing each distributor's compliance report.

In reviewing these documents, we note that ESV has adopted a structured and rigorous approach to determining whether the installed REFCLs comply with the Regulations, including the actions that should be taken if unconditional compliance cannot be demonstrated. It is also evident that ESV is cognisant of the current state of knowledge, theory, industry experience, limitations of the equipment and the numerous technical issues likely to be encountered by the distributors in the REFCL implementation program. We note that this has led to conditional acceptance being granted in relation to zone substations where the distributor has demonstrated to ESV's satisfaction that the distributor has used its best endeavours to overcome a technical issue and has a credible plan for resolving it.

[14] Marxsen, T, REFCL compliance testing activity discussion paper, 2017

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In our view, ESV's approach of addressing technical issues on a case-by-case basis, having regard to the particular circumstances, is appropriate given the newness of the technology and the unique nature of the implementation program. For Tranche 2 and 3 compliance, we note that it may not be appropriate to grant conditional acceptance as the technical challenges are now better understood. Nevertheless, it will be useful for ESV to clarify the (exceptional) circumstances that would lead it to grant conditional acceptance. In addition, we also note that ESV's testing procedures and strategies provide a useful industry resource, in setting out ESV's expectations and in providing a record of how anomalous test results have been addressed.

While the current documents have been prepared for internal ESV purposes, our view is that external versions should be developed and provided to the distributors. We also recommend that ESV should ensure that its proposed treatment of anomalous results is aligned with the distributors' testing policies.

Recommendation A:

ESV should provide its acceptance criteria to the distributors. ESV should ensure its approach to anomalous test results is reflected in the distributors' testing policies to ensure a consistent approach to resolving issues.

2.4. Fault analysis

The 2019-2020 summer is the first period that all Tranche one REFCLs were in operation. To assist us in our performance review, the distributors have provided Total Fire Ban (TFB) day fault statistics over this period, which have been categorised into two fault types, namely Permanent and Transient faults.

During TFB days, the distributors have operated the REFCLs at all Tranche one zone substations in Fire Risk Mode which is the most sensitive setting, with the exception of two AusNet Services' zone substations at Kinglake and Woori Yallock. The REFCLs at Kinglake and Woori Yallock have operated at a desensitised setting due to technical issues, which are subject to the granted time extension as described in section 2.1.

Across the two electricity distribution businesses, there have been 25 permanent faults and 89 transient faults on REFCL protected networks on 2019-2020 TFB days as per the table below. During the 2019-2020 summer a total of 18 TFB days were declared. All of these faults involved phase-to-ground current, where REFCLs are designed to operate to reduce fire risk.

Table 8: Faults associated with RFECL operation

	TFB REFCL Operations	
	Permanent faults	**Transients**
Powercor	13	54
AusNet Services	12	35
Total	25	89

The fault reports provided by AusNet Services and Powercor conclude that there are four fault events out of the 25 permanent faults where a fire start is likely to have been prevented by REFCL operation. This conclusion has been drawn from the analysis of waveform data, event logs and the process that the distributor has followed to locate and repair the fault.

Powercor encountered a total of three faults on the Castlemaine, Camperdown and Gisborne polyphase networks, whereas AusNet Services encountered one fault on the Wangaratta polyphase network. The remaining 21 permanent faults cannot be categorically stated to have prevented a fire start due to a variety of reasons, including local weather conditions or failure to detect the cause of the fault. Although these faults cannot be determined to have prevented a fire start, the results are leading indicators of the operational effectiveness of REFCLs for vegetation related faults. In the absence of a REFCL, these faults would typically be undetected until there was enough fault current to cause an overcurrent protection scheme to operate, which may be too late to mitigate bushfire risk, as evidenced by the research undertaken by the Victorian Powerline Bushfire Safety Program.

The deployment of REFCL technology as a bushfire mitigation tool has proven that locating faults is a common issue AusNet Services and Powercor will continue to face while REFCLs are operating at an increased level of detection sensitivity. At these levels of detection sensitivity, faults typically created from conductor contact with quasi-insulating objects or slight equipment insulation degradation forming a path to earth will result in very low levels of fault current with no visible tracking on faulty equipment. The difficulty of identifying faults and the longer timeframes for restoring supply will contribute to the adverse reliability impact of the REFCL program, which is discussed in further detail in sections 3.3 and 4.3.

Other fault types in addition to phase-to-ground faults can occur on the polyphase network such as evolving, back fed complex, phase-to-phase and consequential faults. The description of these fault types and any benefits REFCLs have in treating them are shown in the table[15] below.

Table 9: REFCL benefits in treating faults

Fault type	**REFCL Benefit**
Transient	A key benefit of REFCL technology is the ability to compensate for transient faults and greatly reduce fire ignition risk without customers experiencing loss of electricity supply.
Undetected	REFCL technology is orders of magnitude more sensitive than traditional protection systems. This means that faults that may have otherwise gone undetected are treated and any fire ignition risk reduced.
Evolving	Faults may begin as single phase to earth and evolve into complex faults involving multiple phases. Due to the high detection sensitivity and low let-through energy, REFCL protection increases the likelihood that the fault is isolated before it can evolve into a complex fault.
Back-fed	Back-fed faults are where a broken conductor is energised back from the load end of the line and are very difficult to detect using traditional protection systems. REFCL protection is effective at detecting and isolating these faults with high sensitivity.
Complex	This may involve multiple phases and earth. A REFCL may provide some benefit, but in most cases faults of this type will involve heavy fault currents that will be rapidly detected and isolated by the traditional protection system.

15 ESV, Powerline Bushfire Safety Bulletin, REFCL Operation, Performance & Limitations (Draft)

Fault type	REFCL Benefit
Phase to Phase	A REFCL cannot detect pure phase to phase faults, but they will be detected and isolated by the traditional protection system. They generally fall under three sub-categories: detached branch, internal equipment and conductor clashing faults. Detached branch faults involve tree branches or other debris that have blown onto powerlines during high wind events. They have the potential to pose fire ignition risk and are more likely to occur on high bushfire risk days, but their rate of occurrence is unclear. Occurrence of internal equipment faults is not expected to be correlated with days of heightened bushfire risk; they likely occur randomly throughout the year. Often they are contained within metal clad switchgear or transformers and do not represent a fire risk. Conductor clashing is more likely to occur in high wind conditions on extreme bushfire risk days. However, directions issued by ESV in 2011 to fit spreaders on distribution powerlines across the state have significantly reduced the likelihood of occurrence in Victoria.
Consequential	Consequential faults are those caused by or as a consequence of other faults. Cross-country faults are one type that is associated with REFCL technology. Cross-country faults may occur when a REFCL compensates for a fault, resulting in the elevation of voltage on the healthy phases. However, recent experience indicates that cross-country faults are rare in Victoria. Other consequential faults can occur due to heavy fault current, such as conductor clashing and failed joints. REFCL technology reduces the risk of these faults, due to the greatly reduced fault current for single phase to earth faults.

To date both distributors have experienced at least one of each fault type listed above. As can be seen from the fault statistics over the 2019 – 2020 summer period, transient faults have occurred at a REFCL operation rate of approximately 78 per cent for phase-to-ground faults. This statistic aligns with industry expectations, as transient faults are typically within a 60-80 per cent range for a network consisting a mix of bare overhead and cabled sections.

Previously undetected faults are associated with the new detection sensitivity levels REFCLs can achieve in comparison to traditional earth fault protection schemes. The assessment of fault information indicates REFCLs have been able to detect these high impedance faults such as vegetation contact with a bare conductor.

Evolving and back-fed faults have occurred on Tranche one REFCL protected networks, although at a much lower rate. Generally, the treatment of these faults benefits from the increased sensitivity of the REFCL protection scheme, further reducing the risk of fire starts.

Powercor experienced a long-duration undetected fault that resulted in a small fire on a non-TFB day. The fault occurred when a fallen branch made contact with a single conductor and tree. From the waveform data it can be seen that the detection threshold for a high impedance fault i.e. 25.4kOhm as per the Required Capacity had not been exceeded during the 2 to 2.5 hour period during which the evolving fault was present on the network. This example highlights that not all fire starts can be avoided, even if REFCLs operate in accordance with the Regulations. It is noted that a REFCL's effectiveness in reducing fire risk was expected to be 90 per cent of earth faults, as shown in Figure 1, section 2.5.

Complex and phase-to-phase faults experienced to date have provided some insights into how these types of faults impact REFCL operations. For example, a fallen tree on Powercor's network had taken all conductors to ground. The fault began as a phase-to-phase fault where upstream fuses had operated resulting in an increase in network dissymmetry[16] due to the imbalance of capacitance downstream of the fuses. The network dissymmetry or neutral voltage exceeded the REFCL operation setting and began to limit the phase-to-ground fault current, eventually identifying and tripping the faulted feeder. Although the REFCL is ineffective in treating phase-to-phase faults, the sequence of events for this complex fault produced a positive outcome.

Consequential or cross-country faults have occurred on tranche one REFCL networks, albeit infrequently. The rate of occurrence of cross-country faults are typically higher for resonant earthed networks where vulnerable assets fail due to the increased voltages inherent to REFCL operation. REFCL operation cannot treat these faults given the second fault caused by the failure of a vulnerable asset essentially leads to a fault consisting of multiple phases and ground. Traditional phase protection devices are expected to isolate the fault.

Given these faults can produce high fault currents that may lead to fire starts and pose a public safety risk, distributors have strategies in place to reduce their rate of occurrence and likelihood of occurring on high bushfire risk days. Distributors reduce the likelihood of cross-country faults by validating the resilience of their assets through proactive replacement of known incompatible assets and stress testing of the whole network as part of the commissioning process. The rate of occurrence of these faults under REFCL in service operation is expected to decline as assets are progressively replaced with new REFCL rated equipment. The risk is further reduced by distributors limiting compensation times, such that the second fault may occur after the first fault has cleared, allowing the REFCL to treat both faults effectively. Finally distributors maintain REFCLs in service throughout all times of the year, such that the risk of cross-country faults occurring is spread out across both low and high bushfire risk days.

Both distributors have experienced restriking faults on their REFCL protected network, which have led to REFCL mal-operations. As these faults typically occur on cabled sections of the network, they are more likely to cause nuisance tripping rather than pose a significant fire risk. From experience to date, REFCLs have not been effective in treating these faults due to inverter control and admittance calculations[17].

In particular, analysis by Powercor has indicated that poor inverter control, the action of controlling and maintaining faulted phase voltage, can result in inconsistent voltage control and ultimately impact the admittance calculations that determine the faulted feeder. In addition, the admittance calculations rely on network voltage and current phasors that consider phase angle. The phase angles in restriking faults are inconsistent, ultimately leading to incorrect admittance calculations. We understand that Swedish Neutral is currently working with the distributors on product enhancements to address this type of fault with the aim of improving the selectivity and reliability of the REFCL's decision making while not adversely affecting i^2t performance. Although the rate of occurrence for this type of fault is unknown, we recommend that the distributors should continue their work to resolve these performance limitations.

16 Network dissymmetry refers to the imbalance of electrical characteristics of a network, namely different capacitance to earth from each of the three phases. The standing neutral voltage is an indicative measure of the imbalance in the network and impacts detection sensitivity of the REFCL.

17 Admittance is the measure of how easily a circuit will allow current to flow. Admittance is the reciprocal of impedance. The REFCL calculates admittance values using measured voltages and currents on a feeder network to determine which feeder contains the fault.

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Analysis of a particular fault on the Powercor network has highlighted that operating at Required Capacity may not always prove to be effective at eliminating fire ignition risk of phase to earth faults. In this instance, a high impedance fault had been detected during the summer period, although the REFCL was not operating at Required Capacity as a TFB day had not been declared. Nevertheless, the sequence of events that occurred and analysis of waveform data demonstrate that REFCL performance, more specifically during diagnostic tests, can vary depending on the non-linear characteristic of the fault. The REFCL has two available diagnostic test methods to locate a fault as described further in section 3.2. Due to the non-linear nature of this fault, the REFCL could not locate the fault using the RCC method which is the diagnostic test method adopted when operating at Required Capacity.

For practical reasons, Required Capacity compliance is assessed against a linear fault resistance, while real high impedance faults are almost certain to be non-linear in nature. The current REFCL product deployed by the distributors utilises a delta admittance scheme to identify the faulted feeder. Fault current is increased in small intervals that allow measurements to be taken to calculate admittance values. The delta admittance value setpoints are determined and configured during REFCL commissioning with a focus to achieving Required Capacity, more specifically Part C.

The determination of admittance setpoints considers specific network characteristics and the linear fault current signature. However, when an intermittent fault current signature is measured as a result of a non-linear fault, the admittance calculation may return a value lower than the expected admittance threshold for a linear fault where more fault current is gradually and consistently released. It must be noted that these performance limitations are more common in high impedance faults and the fault statistics to date do not provide any guidance on whether this limitation is posing a risk to the capability of the REFCL technology to reduce fire risk in accordance with the intent of the Regulations.

The analysis of fault information provided by the distributors indicates that the REFCLs deployed to date are effective in responding to phase-to-earth faults. REFCL performance in real faults has generally been positive and in accordance with the intent of the Regulations. Although the volume of faults is limited, the fault statistics and analysis has highlighted both positive and negative impacts associated with REFCL operation and treatment of different fault types.

In our view, fault information should be assessed annually after each summer period to further quantify the performance effectiveness of REFCLs operating at Required Capacity and at desensitised detection levels i.e. non-TFB days during summer. Fault impedance is considered to be an important statistic and should be captured. Where it is not possible to determine fault impedance from waveform data or the REFCL device, an estimated value should be assumed. Quantifying fault impedances could assist in understanding whether there are any opportunities to optimise REFCL operation by achieving the intent of the Regulations in terms of bushfire risk reduction, while reducing the costs associated with REFCL deployment.

We recommend that the fault information be captured in a common database detailing information such as weather conditions, fault type categorisation, fault impedance and photos from fault crews to assist with understanding local conditions at the time of the fault. Fault reports prepared by the distributors should include additional information specific to REFCL protected networks, including the REFCL operating mode and detection thresholds; network configuration; any abnormal behaviour or sequence of events; fault impedance; and a cross check of actual waveform data against REFCL commissioning and regulatory benchmarks.

Additionally, the fault reports should not only validate that the REFCL device has operated as intended but also comment on the likelihood that REFCL operation has avoided a fire.

> **Recommendation B**:
>
> Fault information should be analysed by each distributor annually after each summer period to assess REFCL performance. Ideally, this analysis should be captured in a common database designed by the distributors to enable data sharing. Fault reports should contain information such as local weather conditions, fault type categorisation, fault impedance, photos, REFCL operating mode and detection thresholds, network configuration, any abnormal behaviour or sequence of events, fault impedance and a cross check of actual waveform data against REFCL commissioning and regulatory benchmarks. In addition to regularly assessing REFCL performance, this information and accompanying analysis should assist in identifying opportunities to optimise REFCL operation to deliver better community outcomes in terms of bushfire risk reduction, reliability performance and costs. Fault reports produced by the distributors should not only validate that the REFCL device has operated as intended, but also comment on the likelihood that REFCL operation has avoided a fire. These reports should be provided annually to ESV in June.

2.5. Are the regulatory objectives being achieved?

In considering whether the intent of the Regulations is being met, it is helpful to revisit the statements and analysis presented in the Regulatory Impact Statement (RIS).

In relation to bushfire risk reduction, the RIS explains that the objective of the Regulations is to reduce the likelihood that electricity distribution powerlines start bushfires[18]. The RIS further explains that the objective is based on the likelihood of electricity distribution powerlines starting bushfires rather than the consequence of a bushfire starting, as:

- All bushfire starts have the potential to cause a devastating bushfire;
- The likelihood of a devastating bushfire is higher on days of higher fire danger;
- The likelihood of a devastating bushfire is higher in higher consequence bushfire risk areas than in lower consequence bushfire risk areas; and
- Once started, the consequence of a bushfire is outside the control of the electricity distributor.

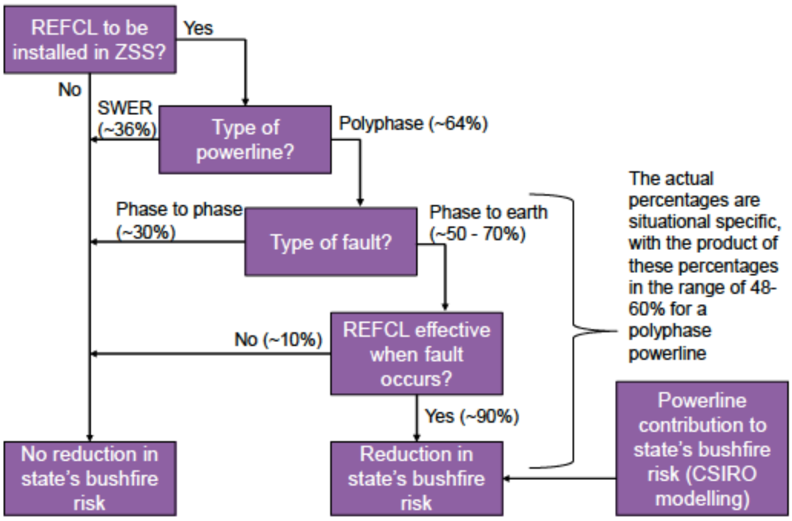
In relation to the expected reduction in risk, the RIS noted that the Powerline Bushfire Safety Program engaged CSIRO to model the impact of installing REFCLs. CSIRO's estimate recognised that:

- The REFCL will not prevent a polyphase powerline supplied by a zone substation starting a bushfire when a phase to phase fault occurs; and
- The REFCL will not prevent a polyphase powerline supplied by a zone substation starting a bushfire when a phase to earth fault occurs under all circumstances.

18 ACIL Allen, Regulatory Impact Statement, Bushfire Mitigation Regulations Amendment, November 2015, figure 6, page 46.

The figure below summarises CSIRO's estimated reduction in bushfire risk for a powerline supplied by a zone substation when a REFCL is installed, noting that the percentages are highly situational dependent.

Figure 1: CSIRO's estimated bushfire risk reduction for a powerline supplied by a zone substation with a REFCL installed[19]



In the remainder of this section, we analyse the performance of the REFCLs based on the compliance and annual testing results for Tranche 1 and the performance of the REFCLs during the summer period.

<u>Initial Capacity Testing and Annual Validation Performance</u>

The following compliance test results were obtained from AusNet Services and Powercor compliance test reports from the nominated zone substations, using the test procedures and methodology described in Section 2.2. The tables below summarise the number of tests undertaken and provides a success rate for demonstrating Required Capacity as of 2 October 2020.

Table 10: Powercor's initial and annual test performance

Powercor	Initial Test 2018		Annual Test 2019		Annual Test 2020	
Station	**Valid Tests**	**Success %**	**Valid Tests**	**Success %**	**Valid Tests**	**Success %**
Gisborne	83	98.7	72	100	20	100
Camperdown	110	94.7	93	100	18	100
Castlemaine	108	96.4	95	100	19	100
Eaglehawk	170	95.5	144	100	36	100
Maryborough	118	99	109	100	20	100
Winchelsea	61	97.2	59	96	36	100
Woodend	174	97.1	145	100	36	100
TOTAL	**824**		**717**		**165**	

19 ACIL Allen, Regulatory Impact Statement, Bushfire Mitigation Regulations Amendment, November 2015, figure 6, page 30.

*Table 11: **AusNet Services initial and annual test performance***

AusNet Services	Initial Test 2018		Initial Test 2019		Annual Test 2019		Annual Test 2020	
Station	**Valid Tests**	**Target Success %**	**Valid Tests**	**Target Success %**	**Valid Tests**	**Target Success %**	**Valid Tests**	**Target Success %**
Barnawartha	78	98.08	-	-	76	98.7	54[20]	100
Kilmore South	-	-	39	98.72	-	-	36	100
Myrtleford	-	-	88	99.7	-	-	72[21]	100
Rubicon A	-	-	91	99.7	-	-	94	100
Seymour	-	-	115	98.9	-	-	108[21]	98.8
Wangaratta	-	-	144	97.7	-	-	126[21]	100
Kinglake[22]	-	-	55	96.8	-	-	-	-
Woori Yallock[22]	-	-	82	91.8	-	-	-	-
TOTAL	**78**	**98.08**	**614**	**97.62**	**76**	**98.7**	**490**	**99.8**

<u>Operational Performance</u>

AusNet Services reports indicate that for TFB days between 21 November 2019 and 31 March 2020, an in service REFCL device operated 47 times, where 35 were transient faults and 12 were permanent faults. Information obtained from AusNet Services indicates that no REFCL network faults caused a bushfire. Over the summer period, AusNet Services' REFCLs operated 323 times, where 268 were transient faults and 55 were permanent faults.

Powercor reports indicate that for TFB days between 21 November 2019 and 31 March 2020, an in service REFCL device operated 67 times, where 54 were transient faults and 13 were permanent faults. Information obtained from Powercor indicates that one REFCL network fault caused a small fire on a non-TFB day. As explained in section 2.4, this fire start occurred as a result of a high fault impedance greater than the Required Capacity detection threshold. Over the summer period, Powercor's REFCLs operated 503 times, where 439 were transient faults and 64 were permanent faults. These faults included operations on one code red day (21/11/19) and 18 TFB days.

Operations conducted by REFCL devices during initial capacity tests, annual validation tests, and during summer periods are summarised below. This total would be substantially higher if it were to include REFCL operations at other times of the year.

20 Due to waterlogged ground conditions, testing of BWA24, the smallest feeder of the 4 BWA feeders, could not be undertaken in August 2020. This feeder will be tested on 16 October 2020.

21 Test reports to be submitted to ESV during October 2020.

22 Extensions of time have been granted for Kinglake and Woori Yallock to 29 April 2021 and 1 November 2020 respectively to enable AusNet Services to undertake remediation works to address the technical issues preventing demonstration of the mandated performance criteria.

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Table 12: REFCL operations

	Powercor	AusNet Services	Total
Initial Capacity Tests (Tranche 1)	824	692	**1516**
Annual Validation	882	566	**1448**
Summer 19/20 Operations	503	323	**826**
Total	2209	1581	**3790**

The results from the initial capacity and annual validation testing by AusNet Services and Powercor indicate a compliance success rate in excess of 90%. In addition, over the 2019-2020 summer no network faults have been identified as causing a bushfire on a TFB day when REFCL protection has been in service. While these results indicate that the REFCL deployment is at least meeting expectations, more operational data on high fire risk days will need to be reviewed over a number of years to confirm with certainty that the regulatory objectives are being delivered.

2.6. Efficiency considerations

The distributors' REFCL deployment programs consist of works and engineering activities required to support or directly demonstrate that Required Capacity is met or exceeded. These works are undertaken while ensuring that network safety, network reliability, personal safety, and compliance with their obligations under various regulations, codes, standards and guidelines, are also met. The key activities include:

- Zone substation augmentation;
- REFCL sizing;
- Asset hardening and replacement;
- Treatment of HV customers;
- Network capacitive balancing activities; and
- REFCL system testing.

<u>Zone Substation Augmentation</u>

REFCLs must be installed at the zone substation and consist of four main components; An Arc Suppression Coil (ASC), Residual Current Compensator (RCC), Grid Balancing Unit and Control System. Considerable engineering activities, including procurement, design, installation, construction, testing and commissioning must be undertaken to ensure that these components can be accommodated in existing brown field zone substations.

REFCL technology essentially changes the earthing philosophy at the zone substation. This change necessitates consequential engineering works, such as implementing new protection and control philosophies to integrate the REFCLs with the existing network beyond the relevant zone substations.

Protection and control devices form a large part of the zone substation augmentation works as existing schemes have traditionally been designed, built and operated on a low impedance or directly earthed philosophy. Existing earth fault schemes installed at the nominated zone substations required changes to accommodate both low impedance and high impedance earthing philosophies. To facilitate the integration of these philosophies additional zone substation augmentation requirements were identified and installed.

A building block approach was established to identify REFCL deployment requirements and the engineering solutions needed to deliver the Required Capacity. This approach was supported by in-depth consultation with European and New Zealand electricity distributors that are experienced with resonant earthing. Furthermore, consultation and product development with equipment manufacturers took place to ensure installed equipment could meet regulatory obligations. We note that product development activities will continue to better integrate the REFCL as operational experience is gained.

In summary, our view is that the engineering solutions adopted for augmentation works at the zone substation have been appropriately scoped in order to achieve Required Capacity.

REFCL Sizing

The REFCL must be appropriately sized in order to achieve the Required Capacity at each zone substation. REFCL sizing relies on accurate 'as constructed' and 'forecast' network line data to determine the amount of capacitive charging current and the impact of other network parameters, such as damping. In some cases, this has led to two or three REFCLs being installed at the zone substation, which further complicates the integration works as each REFCL must be connected to the neutral point of a zone substation power transformer. This has triggered bus and feeder reconfiguration with engineering solutions both within the zone substation and on the polyphase lines originating from the zone substation in order to achieve Required Capacity.

AusNet Services and Powercor have a REFCL sizing policy that utilises engineering calculations developed by electricity industry experts in relation to resonant earthed networks. The rationale that supports assumptions for network damping is based on the individual characteristics of the distributor's respective networks. Powercor has adopted a damping figure between 2.5 and 3.5 per cent and AusNet Services has adopted a figure of 3.5 per cent. Measurements from Tranche one sites indicate that these figures are acceptable, and furthermore, they are within the expected range of 2-4 per cent for Victorian distribution networks.

In our view, the distributors have adopted an appropriate approach in nominating the number of REFCLs required at a zone substation to achieve the Required Capacity.

Asset Hardening and Replacement

When a REFCL is operating, it increases the phase to ground voltage on the two healthy phases to 24.2kV for a period up to 20 seconds. These elevated voltages can stress electrical equipment connected to the 22kV network.

To mitigate any risks created by this stress, AusNet Services and Powercor have undertaken a series of activities which involved a desktop analysis and testing to ensure the network was rated for REFCL operation. Any assets identified to be vulnerable were removed or replaced. We consider the distributors' approach to asset hardening and replacement to be prudent and efficient.

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Zone substation Plant and Switchgear

The distributors have consulted their equipment manufacturers to understand the insulation voltage withstand capability. The feedback from the distributors is that the capability of their 22kV plant and switchgear has been either verified with the associated manufacturers or internal assessment and testing has been undertaken to provide confidence that the equipment can withstand REFCL operational requirements. This issue has not resulted in large scale equipment replacement.

Manufacturers are best placed to know the design and operational limits of their supplied equipment. In the absence of manufacturer advice, the internal assessment and test results the distributors have conducted are appropriate in mitigating any residual risk.

Cables

To identify cables at the highest risk of failure under REFCL operation, the distributors created risk criteria that targeted cables with installation dates unknown or earlier than 1990. Cables serving critical loads were also given special consideration. Cables that did not meet the risk criteria were replaced.

The remaining cables were subjected to partial discharge testing, which is an accepted method of identifying insulation degradation that may lead to accelerated failure when exposed to REFCL operation. We understand that the partial discharge test result criteria developed by the distributors to identify high risk cable assets are bespoke to the REFCL installation program. The distributors have evolved the criteria in light of experience to date and will continue to do so in the remainder of Tranches two and three of the program.

Our view is that the distributors have adopted a prudent and efficient approach to managing the risk of cable failure.

Surge arrestors

Surge arrestors that do not have the specification to meet the minimum voltage requirements of 24.2kV have been replaced with suitable alternatives. A similar approach has also been undertaken for surge arrestors with performance uncertainties. These surge arrestors were subjected to HV tests to understand their operational capabilities under a REFCL operating condition. The results of these special tests were then used to determine whether the surge arrestors would be replaced.

In our view, the distributors' approach to replacing surge arrestors is prudent and efficient.

Insulation Testing

During insulation testing, the distributors used the REFCL to raise the voltage on the 22kV distribution network. This test took place on networks with all assets in service and most customers connected; this aimed to verify all equipment and components could withstand the REFCL operation. The insulation test identified vulnerable assets not captured in the desktop study or perhaps missed in asset replacement works. These vulnerable assets were then replaced as part of REFCL commissioning.

Different parties have taken different approaches to insulation testing:

- Powercor: Applies a Ph-G voltage of 12.7kV x 1.73 to each phase for a minimum of 10 minutes;

- AusNet Services: Applies a Ph-G voltage of 12.7kV x 1.73 to each phase for a minimum of three minutes

The key difference is that Powercor's policy adopts a longer testing duration than that of AusNet Services. Limitations of HV customer connected assets on REFCL networks vary from network to network and were taken into account in insulation test planning, in some cases HV customers were disconnected during the test. In our view longer test durations may be more effective in revealing vulnerable assets that later may cause cross country faults, with associated fire risk. It is noted that AusNet Services has increased the testing duration for its Tranche two installations. In our view, AusNet Services, Powercor and ESV should consider whether a common methodology should be adopted.

Treatment of HV customers

Elevated phase to ground voltages generated by the REFCLs during operation can stress equipment belonging to HV customers on REFCL protected networks. In addition to the financial and safety impacts, failure of HV customer equipment may severely impact the progress of the compliance testing schedule and demonstration of Required Capacity. Distributors have instituted a policy of engaging with affected HV customers to ensure that they understand the technical solutions available to them and their obligations with respect to the Electricity Distribution Code (EDC).

Changes to the EDC were made in August 2018. The timing of the changes meant that the distributors were responsible for HV customers' assets being 'REFCL ready' for Tranche one. For Tranche one, the distributors either replaced the HV customer's underrated equipment or installed HV isolation transformers upstream of the HV customer's point of connection. The HV isolation transformer is an industry accepted solution to protect assets downstream from REFCL operation.

HV customers associated with Tranche two and three REFCL deployment are now responsible for ensuring their own assets are 'REFCL ready'. However, the time taken to make HV customer assets 'REFCL ready' is a compliance risk for the distributors. As a result, the distributors have a responsibility to manage their HV customers to ensure they are REFCL ready in accordance with the REFCL delivery deadlines as far as practicable.

It is noted that the distributors have the authority under the Electricity Distribution Code to switch HV customers off supply if they are not REFCL ready by the required date. In the case where the impact to the HV customer and community exceeds the benefit of reduced bushfire risk, time extensions may be required. To date, appropriate control measures have been identified and implemented so that temporary network arrangements or disconnection of the HV customer is completed when commissioning or demonstrating Required Capacity. These arrangements have allowed compliance testing to proceed, thereby managing the risk of delays as a result of HV customers not being 'REFCL ready'.

Capacitive Network Balancing

Proactive capacitive network balancing is required to reduce network dissymmetry on a REFCL protected network to achieve the Required Capacity. The distributors have initiated programs to balance their networks by:

- Undertaking phase rotations where applicable;

- Adding the third conductor to a single phase spur; and
- Installing balancing capacitors.

In our view the approach taken by the distributors in this challenge is appropriate and has proven effective.

REFCL System Testing

The aim of this activity is to demonstrate that the 22kV polyphase electric line originating from a REFCL protected zone substation meets or exceeds Required Capacity. The test involves purposely initiating a phase to ground fault on the 22kV network that is protected by a REFCL. The behaviour of the REFCL, key network data at the fault site and the zone substation and environmental data are measured and recorded. The information is then documented in a report and submitted to ESV for evaluation. As already noted, our view is that the testing regime and acceptance regime has been effective.

In summary, this section has assessed the key engineering activities initiated by each distributor on their network and zone substations. These works are focused on achieving Required Capacity in accordance with the Regulations. Each of these activities is critical to the REFCL installation program and must be undertaken to achieve this outcome. In our view, the engineering issues encountered by the distributors have been appropriately managed and resolved having regard to the new design, construction, commissioning and operational philosophies that the REFCL technology introduces.

The engineering activities thus far have yielded promising results, with all of Powercor's Tranche one stations achieving compliance. AusNet Services has six Tranche one stations deemed compliant by ESV and two zone substations currently subject to a time extension while harmonics and network damping issues are addressed. In our view, the distributors have acted prudently and efficiently in meeting the requirements of the Regulations.

3. Risks to REFCL program or performance

This section addresses the second element of our scope of work, which is to consider whether there are current, emerging or unforeseen issues that may cause the program timing or technical requirements to be adjusted. In considering this element of our scope of work, we have engaged with the distributors to ensure that we capture their views noting that each distributor has its own internal processes for identifying and managing project risks. In the remainder of this section, we examine the following sources of risk and uncertainty, commenting on each in turn and making recommendations for improved risk management, where appropriate:

- Equipment supplier risks;
- Reliability of the technology;
- Incompatibility of existing network devices (customer supply reliability impacts);
- Change management and engagement;
- Maintaining compliance over time;
- Other technical issues;
- HV customer impacts (both to customers and the program); and
- Impact of Covid-19 or other major events.

In light of the above risks, this section concludes by considering whether there should be any changes to the Regulations.

3.1. Equipment supplier risks

In 2015, the Powerline Bushfire Safety Program undertook four tranches of tests and set up a temporary testing facility next to Kilmore South Zone Substation with testing performed on three REFCL technologies. The aim of the testing was to:

- Review and finalise the draft REFCL performance standard for application in areas of extreme risk from powerline related bushfires;
- Test the performance of the REFCL technologies against a draft performance standard; and
- Confirm the fire risk reduction benefits of REFCL technology with respect to vegetation earth faults.

The REFCL manufactured by Swedish Neutral was found to comply with all elements of the draft performance specification. This favoured Swedish Neutral's REFCL as the product of choice for the distributors, given the mandated requirement to achieve Required Capacity in accordance with the Regulations.

Swedish Neutral is a small, family run company based in Stockholm, Sweden, with limited resources available for the development of the REFCL's hardware and software.

Given the requirements of the Regulations, the supply of REFCLs to the distributors represents a sole supplier risk – that is, a specific product or service which is only available from one supplier. Maintaining a sole sourcing model has potential costs and benefits. The key benefits of the model are simplicity, lower supplier management costs and the potential to obtain lower overall costs (buying bulk). However, potential costs arise from the risk of business closure or that single points of failure are magnified.

For the Victorian REFCL program, issues such as an inability to meet demand or product quality issues could mean that the distributors are unable to meet the compliance standard and increase the risk of incurring civil penalties. In response to the sole supplier risk, both businesses have a similar approach which focused on working closely with Swedish Neutral while supporting product development of alternatives to REFCLs by other manufacturers.

Powercor has focused on collaboration with Swedish Neutral to reduce single points of failure risk. These efforts have resulted in the resolution of software and hardware issues, calibration, RCC tripping, and erroneous admittance measurement. Their efforts to propose new algorithms and key improvements to various functions within the hardware and software have reduced the single point of failure risks and contributed to achieving the Required Capacity for Tranche one within the mandated timeframes. Powercor has also been active in supporting alternative supplier development.

AusNet Services has also worked with Swedish Neutral to resolve the software and hardware issues. In addition, the company has explored the development of an alternative REFCL product with Trench Group, which is part of Siemens. We understand that the Trench Group product has undergone trials on a Victorian network and may be used for future installations. While engaging Trench Group has enabled AusNet Services to potentially mitigate the sole supplier risk, the introduction of a new supplier and new equipment late in the program would present its own risks and challenges. In any event, we note that the distributors have achieved significant improvements in REFCL performance since the REFCL trials in 2015.

Our view is that both distributors have implemented effective risk mitigation measures on the key equipment risk in the REFCL program. Our view is that this risk does not warrant any adjustment to the REFCL performance standard or the program timing. This conclusion is supported by the regulatory compliance achieved in relation to the Tranche one zone substations. It is recommended that the distributors continue to explore measures to mitigate sole supplier risk and seek improvements to Swedish Neutral's REFCL as further operational experience is obtained.

3.2. Reliability of the technology

AusNet Services and Powercor have experienced numerous performance issues relating to the software and hardware components of the REFCL, which have affected the demonstration of Required Capacity at their zone substations. This section discusses these issues, their materiality with respect to the mitigation of bushfire risk, and distributors' efforts to mitigate and/or eliminate these risks.

The key issues are:

- RCC drift and Slow RCC;
- Inverter Calibration;
- Inverter tripping;

- Harmonics; and
- Admittance calculations.

RCC drift and Slow RCC

RCC drift was observed by Powercor at Gisborne during Initial Capacity Testing in May 2018. Powercor's experience indicates that immediately after an earth fault is detected, the RCC inverter is engaged, however, the applied inverter output adjusts away from the correct value resulting in a faulted phase voltage that does not meet Required Capacity. The software function responsible for this issue was identified and immediately disabled. Swedish Neutral undertook an investigation and was able to identify the root cause, which has been rectified in an updated firmware release. Since the update, neither distributor has observed the 'RCC drift' phenomena during any subsequent testing. This issue is considered to be resolved following the release of firmware SVN503.

Powercor also observed the slow RCC issue at Gisborne during Initial Capacity Testing. Powercor's experience indicates that when the REFCL undertook an operational sequence to actively sample the status of an external device, it was incapable of responding immediately to an earth fault. Powercor made contact with Swedish Neutral who advised that the cause was a one way communication channel between the REFCL and RCC inverter. Swedish Neutral amended the sampling behaviour to reduce the likelihood that the engagement of the RCC inverter was delayed. This amendment was also made in firmware update SVN503 and the issue has not been observed by Powercor or AusNet Services in subsequent testing. Therefore this issue is considered to be resolved.

Inverter Calibration

Calibration is an automatic function within the REFCL that must be manually triggered during onsite attendance. It allows the REFCL to scan voltage and current quantities of the network to determine pre-set output parameters for the RCC. These pre-set parameters are then used as a reference by the REFCL when managing phase to ground faults and therefore, there is a direct influence on the effectiveness of the REFCL to reduce bushfire risk and demonstrate Required Capacity.

During the Initial Capacity Test program at Gisborne in May 2018, it was observed by Powercor that, in some instances, the collapsed voltage was not maintained below 250 volts. Following extensive trials and testing, Powercor was able to verify that a bug existed within the REFCL software that prevented it from adjusting the RCC output voltage for faults on the white and blue phases. AusNet Services experienced similar issues at Woori Yallock in August 2018.

Both Powercor and AusNet Services worked in close collaboration with Swedish Neutral to produce an algorithm that optimises the RCC output voltage magnitude and angle based on a feedback of busbar voltage. This has resulted in satisfactory residual voltage levels of the faulted phase at the busbar.

Swedish Neutral provided a beta release of software and included a function that could improve voltage collapse – known as busbar tuning. Powercor tested this firmware during commissioning of the Colac (CLC) zone substation REFCL in March 2019, which showed promising results. In Q3 2019, Powercor was provided with an updated version of REFCL firmware that included an updated busbar tuning algorithm. Swedish Neutral also adopted Powercor's proposed concept, which uses actual voltage measurements of the two healthy phases, the reference L1-L2 voltage, and the neutral voltage. Powercor tested this function at

Winchelsea (WIN) zone substation and found that the function performed effectively to achieve Required Capacity.

As a result of the development, testing and in-service experience with the busbar tuning function, the influence of calibration on REFCL performance is now considered resolved. In our view, an opportunity exists to automate this function rather than rely on a manually triggered process to ensure REFCL operation is optimised when responding to network faults on a dynamic network. It is noted that this recommendation was also contained in the final report of the 2014 Frankston South REFCL Trial.

Inverter Tripping

Inverter tripping occurs after the REFCL immediately detects and manages a phase to ground fault. Once the inverter is tripped, the REFCL system will only rely on the ASC to manage the earth fault, but utilising the ASC alone will not achieve Required Capacity.

Both Powercor and AusNet Services collaborated with Swedish Neutral to develop a solution. Swedish Neutral proposed that a change to the REFCL software through the use of a ‘ramping function’ that would regulate the output of the inverter by initially reducing the output and then increasing (ramping) the output in a controlled manner. Powercor proposed an additional improvement that used a rate of change function for the neutral voltage measurements to make the ramping function more reliable. Investigations by Powercor indicated that the probability of inverter tripping was significantly reduced on the seven REFCL systems operational throughout the 2018-2019 summer period, following the implementation of the inverter ramping method proposed by Powercor.

Further investigations by Swedish Neutral and the inverter sub-supplier were conducted in 2019. The inverter comprises two modules and their investigations identified that when the two modules do not come online at the same time, it could cause one of the modules to become overburdened and result in an inverter trip. Swedish Neutral proposed modifications to the electrical power circuits of the RCC inverter which have been implemented by both distributors and appears to have resolved this issue in Tranche 1 installations. However we understand the issue may have occurred in Tranche two installations due to the impedance from site specific cable installations associated with the output circuit of the inverter. Swedish Neutral has identified the likely root cause and has proposed a solution where hardware kits will be provided to the distributors.

Harmonics

The harmonic content on a network can be supplied upstream or from downstream sources. Although harmonics make only a small contribution to fault energy it can have an impact on the ability to meet the Required Capacity voltage requirements. This is because the fundamentals of a resonant earthed network only allows it to be effective at the fundamental frequency of 50Hz with a harmonic compensation feature ineffective in meeting voltage collapse requirements (magnitude and time). Reliability of this feature especially on large networks has been ineffective with alternative measures undertaken to mitigate the harmonics as described in section 3.6.

Admittance Calculations

Swedish Neutral’s REFCL utilises a delta admittance function to identify which feeder on a station busbar contains a fault. The REFCL is capable of undertaking these measurements by performing an RCC confirmation, which utilises the inverter to gradually increase the faulted-phase voltage until the admittance calculation exceeds a pre-determined threshold. This is the only method that is capable of achieving Required Capacity. The alternative method, known as ASC Confirmation, utilises the ASC only and allows considerably more energy into the fault site, and does not allow the nominated station to achieve Part C of Required Capacity.

AusNet Services experienced this issue initially at Woori Yallock and Rubicon A and conducted a risk assessment on other Tranche one stations. One or both of the following measures were subsequently applied:

- Procuring high specification metering current transformers (class 0.2S CT); and
- Implementing a hybrid operating model to reduce bushfire risk compared to traditional earth fault protection methods.

AusNet Services has also collaborated with Swedish Neutral to enhance software functions.

Powercor encountered admittance calculation issues at Gisborne, Maryborough and Castlemaine initially and in response has applied the following measures:

- Procuring high specification metering current transformers (class 0.1S CT);
- Introducing additional logic to enhance the Station Earth Fault Management (SEFM) controller;
- Implementing a hybrid operating model to reduce bushfire risk compared to traditional earth fault protection methods; and
- Collaborating with Swedish Neutral to enhance software.

An improved algorithm has been developed by Swedish Neutral that improves the accuracy of analogue measurements, however it also pushes the capability of CTs and measuring circuits. Further testing and data analysis on the new software by the distributors and Swedish Neutral has shown that the improved firmware yields satisfactory performance and the delta admittance issue is therefore considered to be resolved.

In summary, the REFCL key reliability issues encountered can be correlated to the unprecedented fault detection, voltage suppression and fault energy requirements in the Regulations. The application of Swedish Neutral's REFCL for bushfire mitigation purposes on complex networks required considerable development of the REFCL product. Our view is that the distributors are undertaking the appropriate measures to identify and mitigate key REFCL software and hardware reliability risks.

3.3. Incompatibility of existing network devices

The distributors have identified that some existing equipment on the network will not be compatible with the REFCL when it is in service. This equipment may affect REFCL operation directly causing mal-operation, or the incompatibility may cause mal-operation of the equipment itself.

<u>Automatic Circuit Reclosers (ACRs)</u>

Prior to the installation of the REFCL, ACRs operated when the fault current exceeded a pre-set threshold. In a system with a REFCL installed, the response of the REFCL to an earth fault increases current flow in healthy feeders. This may lead to tripping of healthy feeders or groups of feeders when the REFCL operates. To mitigate this impact, the ACRs must be able to measure the direction of current flow and/or differentiate when the earthing configuration at the zone substation is of high impedance (due to REFCLs) or of low impedance (due to NERs). In a REFCL network, this is the one differentiating factor that will enable the ACRs to detect the difference between actual fault currents (in a faulted feeder) and increased current flow (in healthy feeders).

Both distributors have identified this issue and have been undertaking a proactive program that identifies and replaces or upgrades ACRs on REFCL protected networks. The new or upgraded ACRs include algorithms to address the blocking of traditional earth fault and sensitive earth fault protection as well as through-fault detection to prevent mal-operation on REFCL configured networks. Additionally, the ACR program will aim to incorporate sensitive and reliable detection of earth faults downstream of the ACR while the fault is being treated by the REFCL. Currently, there is no ACR product that has been widely deployed that can reliably detect the same 0.5A fault current the REFCL device is treating.

Our view is that the distributors' proactive ACR program has efficiently managed the risk of mal-operation due to the introduction of REFCL technology. Development with existing ACR suppliers is currently underway, with some limited trials conducted. Trial results are positive and indicate that smarter ACRs can be developed and deployed on a wider scale to improve general fault detection, and more importantly, achieve better integration with REFCL fault treatment.

Distribution Feeder Automation

AusNet Services employs a Distribution Feeder Automation (DFA) system as part of its commitment to improve customer supply reliability. Using an algorithm, the technology is able to quickly locate and isolate a faulted section of the feeder and, using a system of remote controlled switches, the technology is able to redirect the electricity supply to restore power safely so that a minimum number of customers suffer prolonged supply interruptions. Overall, the DFA system is incompatible with an in service REFCL for the reasons outlined below:

- The DFA relies on fault targets from remote controlled gas switches, ACRs and feeder relays. The feeder targets can be replaced by REFCL feeder fault indications. However, gas switches cannot detect earth faults on resonant earthed networks. Without these fault targets to feed the DFA algorithm, the faulted section cannot be reliably identified.

- During peak bushfire risk season, the DFA algorithm may not be compatible with an in service REFCL, since redirecting electricity supply may cause the network to migrate away from the configuration in which Required Capacity can be achieved. A change in the network configuration can affect the performance of the REFCL given its parameters have been optimised to achieve Required Capacity for a specific network characteristic.

AusNet Services is addressing the DFA performance issues by identifying and replacing non-compliant remote controlled gas switches and modifying the DFA algorithm to operate with the REFCL in service. We note that this is a network supply reliability issue which does not directly affect AusNet Services' REFCL installation program.

Fuses

Both distributors have completed works to mitigate the impact that fuses have on REFCL protected networks. Currently, fuses are separately installed on each phase of a line. Operation of one or two fuses will lead to increased levels of network dissymmetry which may cause the REFCL to mal-operate and incorrectly trip the feeder. This may be troublesome for phase-to-phase fault events which can result in the loss of two fuses.

AusNet Services and Powercor have responded to this risk by undertaking protection studies and replacing existing fuses with solid links, fuse savers or ACRs. We note that these works are concerned with network supply reliability and do not affect the achievement of Required Capacity.

HV Regulators

Both distributors utilise open-delta and independently controlled closed-delta regulators that are incompatible with REFCL operation. This is because the regulators create dissymmetry on the network that may cause the REFCL to operate when no fault is present. Both distributors have replaced these regulators with three-phase regulators that minimise neutral voltage fluctuations as a result of voltage regulator operation. In addition, single phase controllers must be replaced with a three phase controller so that voltages across all phases remain balanced, to avoid generating dissymmetry that may cause the REFCL to operate and trip a feeder when no fault is present.

Zone substation and feeder protection

Both distributors utilise feeder overcurrent protection that has been set to accommodate solidly grounded or low impedance grounded networks. Similar to the ACRs, the introduction of REFCL technology necessitates the updating of these schemes to include blocking functions of the existing protection when a REFCL is in service.

Given the complex nature of the REFCL, there are a number of failure mechanisms that could influence earth fault protection detection levels. Strategic spares should be held to enable failures to be addressed as quickly as possible. In addition, if the controller of the REFCL fails, then the zone substation and feeder protection schemes should be able to operate for a resonant earthed network without the power electronics i.e. Arc Suppression Coil only. In this instance, the fault current will not be reduced to Required Capacity levels, although fire risk will still be lower than would occur with traditional earthing at the zone substation. The distributors are currently exploring ways to better integrate the REFCL in such cases through the use of protection functions in the feeder protection relays.

In summary, our view is that the distributors have been proactive in initiating programs to replace or upgrade systems or equipment which have been identified as being incompatible with REFCL protected networks. All programs have either been implemented or are being progressed and do not pose a risk to program timing or justify a need to adjust REFCL technical requirements.

Recommendation C

It is recommended that distributors ensure that they hold sufficient strategic spares to ensure that REFCLs can be returned to service in the event of a component failure. In addition, distributors should ensure that the impact on REFCL performance as a result of a component failure is minimised. In this regard, the distributors should continue to explore ways to better integrate the REFCL and provide back-up protection which utilises the Arc Suppression Coil in the event that the REFCL controller fails.

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3.4. Change management and engagement

REFCL deployment involves significant technical change, which has required active management by the distributors to address internal change management challenges and engage with ESV and industry stakeholders in a timely and effective manner.

Our assessment is that the distributors have committed significant resources to the effective management of the REFCL program. These efforts have included change management initiatives to assist internal engineering and operational staff. Furthermore, external stakeholders such as HV customers have been continuously supported throughout the REFCL program.

In our view, distributors will need to undertake ongoing training to maximise the customer benefits from the REFCL program. In particular, further training and supporting infrastructure investment will be required to improve fault identification and fault analysis, especially as more REFCLs are installed. Improved outcomes for customers over time will require first responders in the control room and fault crews to reliably and consistently capture data on all permanent faults. In our view, better data capture is essential to enable distributors and ESV to analyse REFCL performance and optimise future operation.

ESV's governance framework acknowledges that there are many challenges associated with the REFCL program. ESV has supported the distributors appropriately in demonstrating compliance with the Regulations. This has included collaboration on compliance testing and acceptance methods, facilitation of technical working groups and general reporting. Non-conformance issues have been addressed by ESV on a case-by-case basis, which we consider to be a pragmatic and prudent approach given the limited REFCL operational experience. In our view, this approach has contributed to the timely delivery of the program in accordance with stakeholder expectations.

In relation to stakeholder engagement, we note that the REFCL implementation program is a major infrastructure investment undertaken on behalf of electricity customers and the broader community to reduce the risk of bushfire ignitions from electricity assets. Given the magnitude of the investment, it is important for stakeholders to understand the scope of the program and the extent to which it is expected to reduce bushfire risk. In this regard, we note that both distributors have developed useful information that promotes stakeholders' understanding of the REFCL program and its objectives.

We recommend that ESV provides better information on its website in relation to the overall progress of the REFCL program, including the current status of the program. By making this information publicly available, ESV will enable stakeholders to gain a better understanding of the technical challenges involved and the efforts by all parties to resolve them. In our view, this further information will assist in building community confidence in the REFCL program.

Recommendation D:

It is recommended that ESV provides better information on its website in relation to the overall progress of the REFCL program, including the current status of the program in terms of compliance and time extensions. The information should provide a high-level summary in a customer-friendly format.

3.5. Maintaining compliance over time

Following initial capacity testing, the distributors are obliged to demonstrate compliance annually prior to each fire season by conducting primary earth fault testing similar to the initial capacity testing. The testing is conducted to ensure that the REFCLs continue to deliver the benefits of bushfire ignition risk reduction.

Change Management

As the installation program progresses towards its completion by 1 May 2023, the amount of resources required to demonstrate compliance will increase. By the end of the program the three distributors (AusNet Services, Powercor and Jemena) are required to demonstrate Required Capacity for 45 stations every calendar year. Therefore, the distributors will need to manage the transition from ‘delivering compliance’ to ‘maintaining compliance’.

Both AusNet Services and Powercor have implemented change management programs to ensure that REFCL operation is appropriately understood and integrated. These change management initiatives aim to cement the management of REFCLs as a' business as usual' process.

The key strategies utilised by the distributors include:

- Engagement with relevant stakeholders;
- Communication;
- Training; and
- Continuous improvement.

The change management program is essential given the shift in the distributors’ earthing philosophy from direct earthed/NER system to a resonant earthed system.

Network Characteristics – Increasing Network Capacitance

As previously discussed in Section 2.6, sizing the REFCL is a critical activity. Over time, Victoria’s 22kV distribution networks will increase to accommodate population growth, especially in Victoria’s growth corridors. The installation of additional overhead lines and underground cables will be required to meet growing supply needs. The use of underground cables produces a high level of capacitive network current, which will then require the distributors to assess the capability of the existing REFCL system to reduce bushfire risk.

Currently, a solution exists for one or two REFCLs at a zone substation but not any more than that. If more than two REFCLs are required at a zone substation, a distributor may be unable to demonstrate compliance unless the three REFCL solution currently under development is proven.

The use of both capacitance isolation and installation of a new zone substation has been proposed by the distributors as solutions to this issue. Technically, these are credible solutions in reducing network size, however the latter comes at a significant cost and may not provide an appropriate return in terms of the expected benefits in reducing fire risk.

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Network Characteristics – Damping

Network damping is a measure of the resistive losses in the 22kV distribution network. Operational experience to date indicates that damping is generally higher where there is a higher proportion of underground cable in remote areas of the network. Damping also varies considerably depending on weather conditions, increasing during wet weather. As described in Section 2.6, a high damping value limits the capability of the REFCL device to detect high impedance faults in accordance with the Regulations.

Installing an isolation transformer on the feeder is currently being explored by the distributors as a way of reducing damping contributed by remote underground cable.

There is no method to pre-emptively obtain accurate damping values through modelling or calculations. To date the distributors have relied on assuming that damping values lie within a bounded range of 2 to 4 per cent, based on experience. However, AusNet Services' Kinglake station has shown that there are outliers, where damping on its 'system normal' configuration was measured at 7 per cent. The single outlier in Kinglake has delayed the demonstration of compliance, and led to a time extension. AusNet Services plan to reduce the network capacitive current of the network by isolating cabled sections of the feeder causing the excessive damping.

The risk to the distributors is that the damping value has been based on an assumed bounded range, and the true damping value is not known until it is measured by the REFCL. Obtaining the true value post installation may impact compliance, as seen at Kinglake station. To mitigate the risk to the program and to maintain compliance, it is recommended that the distributors explore methods to better predict damping values before REFCL installation.

Compliance Network Configuration

Currently, it is accepted that compliance should be demonstrated by each distributor on a 'system normal' network configuration - i.e. that which applies during high fire risk weather. The 'system normal' configuration is agreed between the distributors and ESV prior to compliance testing, and Required Capacity is certified for this configuration only. It is noted that on TFB and code-red days, network switching is limited and the 'system normal' configuration used during demonstration of compliance is the intended network configuration on these high risk days.

It is understood that distribution networks are dynamic, as network configurations can change as a result of fault events, repair or maintenance works. Any deviation in network configuration can impact REFCL performance. Maintaining a network configuration to optimise REFCL performance can impact feeder transfer, repair or maintenance works. In our view, changes in network configuration may create challenges in maintaining compliance over time and it would be impracticable to demonstrate Required Capacity on a variety of network configurations.

In summary, while a number of challenges will arise in terms of maintaining compliance, these challenges do not warrant a change in the REFCL implementation timetable or the definition of Required Capacity. This issue raises broader questions regarding the optimisation of REFCL deployment over time so that customers obtain the best outcome in terms of bushfire risk mitigation, reliability and cost.

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In our view, the current framework should provide sufficient flexibility through the technical exemption regime and through the annual Bushfire Mitigation Plan to ensure that investment in and operation of REFCL technology is broadly aligned to the intent of the Regulations.

Recommendation E:

It is recommended that the distributors explore methods to better predict damping values accurately, and remove the reliance on the bounded range currently adopted to mitigate the risk to the program and to maintaining compliance.

3.6. Other technical issues

Three other technical issues that are worthy of further consideration are:

- Identification of vulnerable assets;
- Treatment of harmonics; and
- Busbar voltage vs fault site voltage.

We discuss each of these issues briefly below. We note that these technical issues do not have any implications for the current timing of the REFCL program or the definition of Required Capacity.

Identification of vulnerable assets

Currently, each distributor has outlined a strategy to proactively identify, test, upgrade or replace electrical assets which cannot withstand REFCL operation. When the assets undergo insulation testing through commissioning or are placed under stress by REFCL operation, it is assumed that this process will further identify vulnerable assets before the peak fire season. In some instances the vulnerable assets have only been identified during the commissioning phase, which has an impact on the compliance schedule. Currently each distributor is undertaking initiatives to locate high impedance faults and vulnerable assets prior to commissioning. These initiatives include:

- Equipment trials which can identify and locate faults with an impedance higher than 25kOhm.
- Early fault detection systems which can predict asset failures by type, and locate them.
- Installing more sectionalisers to increase the granularity of isolation options on feeders.

These initiatives are currently still in the trial phase, and they will not be implemented before the end of Tranche two.

Treatment of Harmonics

Harmonics exist on all networks and are generated by customer loads and network assets. The presence of harmonics poses two risks. Firstly, a compliance risk to reduce the faulted phase voltage at the zone substation

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busbar to less than 250V and secondly and more importantly the risk of increased fire probability in powerline faults.

During compliance testing at several Tranche 1 stations, it was recognised that system harmonics impact the ability of the distributors to meet the compliance target given the target is an RMS value. Both distributors were able to demonstrate that if the harmonic content was removed, then the compliance with respect to the voltage collapse component could be achieved. Therefore, the effectiveness of the REFCL is limited to reducing only the fundamental frequency earth fault current. The earth fault current that results from harmonics is unaffected. Additionally, Powercor discovered that the use of the enhanced busbar tuning can reliably collapse the fundamental voltage such that the RMS quantity is within compliance limits. In cases where the compliance limit was not achieved, the materiality of the harmonic content was assessed to determine the increased fire probability.

The materiality of harmonic voltages were investigated by the distributors. Powercor assessed fault location voltages at 41 Tranche 1 primary fault test sites. Their findings indicate that any residual voltage higher than the busbar was comprised predominantly of the fundamental component. The key findings of their investigation were:

- Any material increase in residual voltage at the fault site is comprised (predominantly) of the fundamental frequency.
- Harmonics on the 22kV busbar did not materially increase the voltage at the test location and therefore could not materially increase the residual fire risk.
- If the 250V limit is exceeded due to low load harmonics, the residual fire risk is lower than if this limit were exceeded due to high fundamental voltage. This is because fundamental voltage rises along the line due to line impedance, while harmonics are of a similar magnitude throughout the network.

Powercor has proposed an approach which seeks to quantify the residual fire risk posed by harmonics when the absolute busbar voltage exceeds 250V[23] for as long as THD levels remain within the limits of the EDC. In our view, this approach seeks the best compromise between reducing bushfire ignition risk and providing benefits for the community, while efficiently deploying capital investment.

<u>Busbar Voltage vs Fault site Voltage</u>

The discussion in relation to harmonics has continued to highlight another important technical issue that has been researched by both distributors through testing on the network. This issue relates to the evaluation of voltage measured at the busbar versus voltage measured at the fault site location as being the best measure of reducing fire risk.

The Regulations have been written such that the faulted phase voltage collapse should be assessed at the zone substation busbar. This is not only for practical reasons, but to provide clarity when assessing compliance, given that fault site voltage at remote locations can be influenced by a variety of dynamic network

[23] The PBSP REFCL technologies final report (https://www.energy.vic.gov.au/__data/assets/pdf_file/0021/41709/PBSP-REFCL-technologies-Kilmore-final-report-151204.pdf) notes the 250V limit at the zone substation busbar allows for a safety margin that covers remote fault site voltages up to 1,000V, where the risk of fire ignition is low.

characteristics such as load on the feeder, REFCL network parameters and electrical distance from the zone substation.

Consultation with REFCL suppliers indicated their concern in focusing on reducing faulted phase voltage at the busbar, given the real fire risk is at the fault location. Prior to using REFCLs as a bushfire mitigation tool, REFCLs were designed to limit the energy released at the fault site. However, as a result of how the Regulations have been written, REFCL design has been modified to satisfy Victorian compliance requirements. A question remains regarding the effectiveness of REFCLs in achieving fault suppression at the fault location, the impact it will have on busbar voltage at the zone substation, the consequential operating modes, and the resultant fire risk reduction benefits.

We have reviewed this issue in detail while considering responses from the distributors and REFCL suppliers. In our view, there needs to be more focus on fast reduction at the fault site when a powerline fault occurs on a high bushfire risk day to maximise the benefits of REFCL technology in reducing fire risk.

Recommendation F

It is recommended that the distributors continue to collaborate with REFCL suppliers to develop fast voltage reduction and reduced energy released at the fault site with the objective of further reducing bushfire risk. The distributors are required to demonstrate their REFCL device can be operated at Required Capacity however if the REFCL can be configured and operated differently to deliver an improved risk reduction at the fault site then this should be explored.

3.7. HV customer impacts

As described in Section 2.6, some 22kV assets inside HV customer premises may be stressed by the voltage levels associated with REFCL operation. Both AusNet Services and Powercor have instituted a policy and strategy for all affected HV customers.

There are currently three viable technical solutions which are available to HV customers. These are:

- Installation of an isolation transformer;
- Hardening; and
- Conversion to low voltage (LV) or 66kV supply.

The installation of an isolation transformer at the HV customer's point of connection electrically isolates the HV customer's electrical facilities from the distributor's network. The isolation transformer will thereby ensure that customer assets will not experience voltage disturbance associated with REFCL operation.

Hardening requires identification of electrical assets that do not have the capability to withstand an elevated voltage of 24.2kVrms. These assets will be identified, tested, and replaced if required. Each distributor currently has a different insulation testing policy with which their respective HV customers must comply. It is a recommendation of this report that the distributors consider aligning their insulation testing methodologies. Additionally, hardening requires the distributor to have full visibility of HV customer networks given that those networks can impact REFCL performance. This requirement has been included in the EDC as an obligation on the HV customer to provide necessary information at the request of the distributor to ensure REFCL performance is not adversely impacted.

The third solution is to convert the system voltage to low voltage (LV) or a higher voltage such as 66kV meaning the nominal operating voltage will not be protected by the REFCL. This prevents voltage stress on HV customer assets during REFCL operation as the REFCL only operates on the 22kV network.

Prior to Tranche one of the installation program, ESV commissioned a study[24] to examine the impacts on HV customers of the REFCL program. At that time, the onus was on the distributors to ensure that all HV Customers' assets were REFCL ready, in accordance with the EDC obligations at that time. It was recognised that HV customers may incur significant costs to become REFCL ready. Therefore, the Victorian Government created the High Voltage Customer Assistance Program (HCAP) fund to provide financial assistance to Tranche two and three HV customers whose equipment would be directly affected. The HV customers were engaged and assisted by the distributors to assess their assets and select a technical solution which directly met their needs.

On 20 August 2018 the Essential Services Commission (ESC) published amendments to the EDC (version 9A) to cater for REFCL devices on the distribution network. The key amendment relates to clause 16 of the EDC which clarified the obligation on HV customers to ensure their electrical assets are able to withstand REFCL operations. Effectively, for Tranches two and three, the HV customers will be responsible for ensuring that they are REFCL-ready.

In Tranche one, we are not aware of any outstanding issues from HV customers relating to the distributors' REFCL installation programs. In Tranche two there have been a range of issues relating to the readiness of HV customers. The distributors continue to actively engage with HV customers and ESV to facilitate compliance with the EDC requirements, including the investigation of options such as temporary transfers, HV customer disconnection or time extensions.

In relation to compliance testing, the distributors and ESV work cooperatively to ensure that any HV customer readiness issues do not lead to undue delays. The parties ensure that the compliance testing documentation records show any outstanding HV customer readiness issues have been addressed. In some instances, ESV may require testing to be repeated once the HV customer works have been completed.

In our view, ESV and the distributors have adopted a pragmatic and efficient approach to addressing HV customer readiness issues. Given the experience to date, the risks arising from HV customer readiness do not warrant any changes to the Regulations.

3.8. Impact of Covid-19 or other major events

In response to the Covid-19 pandemic, ESV has revised its processes and established a new method of ensuring that REFCL compliance testing could continue under the Covid-19 restrictions put in place by the Victorian government.

24 https://esv.vic.gov.au/wp-content/uploads/2017/06/HV-customer-assets-and-REFCL-protected-networks-report-20170621.pdf

The documents “REFCL Compliance Testing Under Covid-19 Restrictions” and “REFCL Compliance Testing procedure” describe the method to observe compliance or undertake annual validation tests remotely. The key objective is to eliminate the risk of personnel contracting Covid-19 or asymptomatic personnel infecting regional communities. Powercor and AusNet Services have embraced the remote observation method as outlined in ESV’s documents, with annual validation testing continuing.

The other risk associated with the Covid-19 pandemic is equipment delivery risk. Both distributors are continuing to work with their key equipment suppliers to ensure that flight restrictions do not impact the REFCL program schedule. Additional measures such as frequent progress tracking and remote testing and acceptance of equipment are currently being implemented by the distributors.

AusNet Services has also been impacted by the Victorian bushfires of early 2020. Bairnsdale zone substation and Wodonga Terminal Station supply areas were impacted by the bushfires and in some cases REFCL program activities such as line balancing were impacted as lines were rebuilt and re-surveyed.

Our view is that the distributors’ existing risk mitigation measures in relation to Covid-19 are effective, with only minor delays to program activities expected. Equipment suppliers and ESV continue to be engaged throughout the program to mitigate delivery and testing risks. Based on the current evidence, while Covid-19 does not warrant a change to the REFCL implementation program, the situation remains fluid and it is conceivable that a delay in the program may be necessary in the future.

3.9. Should the Regulations be amended to mitigate risks?

As explained in the previous sections, the distributors have taken action to manage the known risks to the delivery of the REFCL program. We note that a number of these risks are not entirely within the distributor’s control, most notably the sole supplier risk; the reliability of the technology; HV customers; and COVID-19.

The Grimes Report recommendation 27 specifically suggested that this report should consider whether any emerging issues necessitated adjustments to REFCL program timing or technical requirements. In our view, while it is conceivable that one or more of the risks identified in this report may warrant a time extension, no change is warranted at this time. In reaching this conclusion, we note that:

- The risks are being managed effectively by the distributors, with the support of ESV, to the extent possible; and
- The time extension and exemption regimes provide flexibility to address emerging issues as they arise.

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4. Additional benefits or opportunities

This section addresses the third element of our scope of work, which is to consider whether there are any unexpected additional benefits arising from the REFCL program, or opportunities to obtain further benefits in the future. In considering these questions, we have worked closely with the distributors to understand their operational experience to date and the potential to exploit the REFCL technology to deliver future benefits. This section considers the following questions:

- Have the distributors identified any unexpected benefits of installing REFCLs?
- Are there any opportunities for future benefits that could be obtained?
- What, if any, changes should be made to maximise the benefits from REFCL technology?

Each of these questions is considered in turn, below.

4.1. Unexpected benefits

The implementation of REFCL technology involved the transition from low impedance or solidly earthed networks to resonant earthed networks. The benefits of REFCL technology or resonant earthing has been widely understood in other countries, predominantly in Europe.

In Victoria, unexpected benefits associated with the REFCL deployment program have centred on the achievement of a new best practice in earth fault treatment. Improvements to impacted assets such as primary plant, protection and control systems, and lines equipment has yielded a more robust electricity distribution system to cater for the increased voltages under REFCL operation. Additionally, innovative engineering solutions have been implemented to deliver a required outcome, and have also enabled the distributors to adapt to developments in earth fault treatment methods through product development and network asset integration activities. As more operating experience is gained, it is expected that further benefits will emerge given the protection sensitivity levels in operation on the network.

Another benefit has been the ability to reduce fire risk for complex faults as described in section 2.4. Prior to this fault event, knowledge of REFCL technology effectiveness for these faults had been limited to scenarios where simultaneous contact is made between multiple phases and earth. The fault event highlighted that complex faults are not limited to a single scenario and can reduce fire risk if the complex fault results in enough network dissymmetry to trigger REFCL operation.

4.2. Opportunities for future benefits

The primary opportunities to achieve future benefits are:

- Network reliability;
- Harmonic compensation;
- Managing asset failure risk; and
- Improved safety outcomes.

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Network reliability

Network reliability has deteriorated as a result of REFCL implementation, but there is potential to achieve better reliability outcomes in the future.

As a result of REFCL deployment and operation, network performance in terms of momentary outages has improved as expected. Network reliability in relation to sustained outages, however, has been adversely affected, thereby impacting the distributors and HV customers in a negative way. This adverse outcome is driven by the sensitivity levels achieved with faults becoming increasingly challenging to identify, locate and repair. This results in an increase in both customer minutes off supply and the number of customers off supply, as the REFCL trips the feeder circuit breaker located at the zone substation.

The distributors are currently working on solutions to improve network reliability, as described in section 3.3. The principal impediment in achieving reliability improvements relate to ACR product development and the duration of REFCL operation for a fault condition. Currently, once a phase-to-ground fault is detected, REFCL operation typically takes less than a minute before a feeder circuit breaker is tripped. However, the existing field devices used to identify the fault location (to reduce the number of customers impacted) may require additional compensation time if field device algorithms cannot detect faults using the transient response or fault management signature of the REFCL. Currently, the EDC allows distributors to operate a REFCL indefinitely, however detailed risk assessments are required to ensure safety risks are mitigated when considering longer compensation times.

An impediment to operating with longer REFCL compensation times is the expectation that when a fault occurs on a polyphase network, a protection device must isolate the fault as quickly as possible to reduce the safety risk posed by an unsafe situation. REFCL technology essentially neutralises the fault current and, by definition, does not isolate the fault. It has the ability to maintain supply to customers, hence highlighting a potential benefit of the technology. However the potential benefits from the operation of a REFCL for prolonged periods will not be uniform across all fault types encountered, let alone on dynamic polyphase networks. To quantify this benefit, REFCL technology needs to be in service as often as possible which may increase customer impacts. Operating data obtained can then be further assessed to understand the benefit of continuous or prolonged compensation times.

Another impediment to achieving better reliability outcomes is the prolonged time to fault-find, given equipment damage is minimised and, in most cases will not be visible to response crews. There are limited tools such as imaging scanners or cameras available, and these are yet to be proven effective in assisting fault finding of electrical assets. However it is understood that other products are being trialled to locate faulty equipment; these products include early fault detection scanners which monitor incipient faults in real time. There is a benefit in using this technology in conjunction with REFCLs given the sensitivity range of these products and the combined ability to identify, treat and locate a high impedance fault. It is recommended that the distributors continue to explore and trial other technologies and fault finding tools to assist in improving network reliability impacts from sustained outages. It is anticipated that the success of such trials should warrant the deployment of these technologies to realise the benefits.

Recommendation G:

It is recommended that the distributors continue to explore fault locating technologies, including fault finding tools, to assist in improving network reliability impacts from sustained outages.

Harmonic compensation

Harmonic compensation is a feature of the current REFCL device supplied by Swedish Neutral. It has the potential to mitigate harmonics in phase-to-ground faults that occur on polyphase networks. This potential was identified during the PBSP research trials[25] due to the potential fire risk posed by harmonics in phase-to-ground faults. To date, the harmonic compensation feature of the Swedish Neutral REFCL device has not been considered effective in the treatment of harmonic content associated with phase-to-ground faults. This is for several reasons, including the amount of harmonics to mitigate, REFCL design, compensation response time and consequential load demand drawn by the device for this feature.

Managing asset failure risk

The REFCL has the ability to manually control phase-to-ground voltages on polyphase networks, and it can be used to perform HV testing activities such as partial discharge testing. This function has been widely used in Europe to detect incipient dielectric collapse (insulation that is about to fail) with HV equipment. Additionally, in some cases where partial discharge is present the REFCL has been configured to adjust phase-to-ground voltages, to deliver benefits that include deferring asset failure and allowing critical assets to remain online until the asset is repaired or replaced.

Partial discharge testing methods can either be completed online or offline. Traditional partial discharge testing is completed offline and is less convenient as the equipment must be disconnected. Using the REFCL to increase network voltages to identify partial discharges avoids disconnection of equipment and temporary generators to be connected which can be costly and time consuming. Utilising the REFCL to realise partial discharge testing benefits depends on the distributor's expertise and capacity to complete the tests, given these tests are typically completed by external specialists and requires special measuring devices.

Improved safety outcomes

Our review identified one instance where a work crew (not associated with the electricity business) accidently and repeatedly made contact with an overhead line, which resulted in REFCL operation. In this instance, the work crew did not notice the contacts due to the absence of any sparks or noise that would typically be expected when contacting a HV line. As a result of REFCL operation, no crew member was injured and no equipment was damaged. This represents a significant safety benefit of REFCL technology, in the form of a significant reduction in electrocution risk faced by workers and the community.

Powercor and United Energy have highlighted the safety benefits of REFCL technology. Those distributors have implemented additional protection and control schemes to integrate REFCLs while live line works are being conducted on REFCL protected networks. Before REFCL deployment in Victoria, all distributors applied live line sequence on feeders where live line works were being conducted. This scheme trips the feeder circuit breaker automatically when a fault is detected on the feeder, and suppresses auto-reclose functions of field devices where live line sequence has been enabled. These actions minimise risk to any live line workers in the event a fault occurs, through isolation of the fault as quickly as possible. This is a potential area where a uniform approach should be adopted to ensure safety benefits across all REFCL installations are maximised.

25 PBSP, REFCL Technologies Test Program, 4 December 2015

REFCL technology has the ability to rapidly reduce energy released at the fault point and then potentially increase the fault current through the fault confirmation sequence. Given this ability, there is an opportunity for the distributors to review and align live line works practices on REFCL protected networks. We recommend that the distributors review their approach to integrating live line sequence on REFCL protected networks, with a view to reducing safety risk through the adoption of a common, best practice approach.

Recommendation H:

We recommend that the distributors review and align their approach to maximise the benefits from reduced electrocution and the integration with live line sequence on REFCL protected networks.

4.3. Should the Regulations be amended to maximise benefits?

The distributors' principal focus has been achieving Required Capacity in accordance with the Regulations to deliver bushfire risk mitigation and avoid civil penalties. As explained in this report, based on limited operational experience to date, the REFCL technology appears to have operated in accordance with the Regulations. Most importantly, there have been a number of specific examples where REFCL operation may have prevented a bushfire and produced improved safety outcomes.

Given the newness of the REFCL technology, it is likely that the distributors will continue to find opportunities to enhance the benefit of REFCLs to customers in terms of bushfire risk reduction, reliability performance and costs. At this stage, there is no compelling evidence of any need to change the existing Regulations to enable benefits to be maximised. In addition, we note that the current framework, including the technical exemptions and Bushfire Mitigation Plan, provides sufficient flexibility to ESV and the distributors to optimise REFCL technology for the benefit of electricity customers and the wider community.

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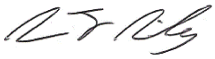
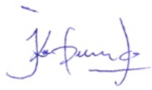
Document History

Revision	Description/Action (Review/Approval/Issue)	Name/Signature	Date
0	First issue	Roger Riley  Jon Bernardo 	14 October 2020

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Appendix A – Glossary

22kV	22,000 volts – the line voltage on most of Victoria's electricity distribution network
50Hz	50 cycles per second – the frequency of Victoria's electricity distribution network
AC	Alternating Current – an electrical current which periodically reverses direction and changes magnitude continuously with time
ACR	Automatic Circuit Recloser – typically a pole mounted switch on Victoria's electricity distribution network
Admittance	The reciprocal of impedance – a measure of how easily a circuit will allow current flow
Amp, A	Amperes – the unit to measure flow of electric current
ASC	Arc Suppression Coil – a REFCL component used in all resonant earthing schemes
AST	AusNet Services – an electricity distributor in Victoria
BMP	Bushfire Mitigation Plan – a Distributor's plan to mitigate the risk of fire ignition associated with their electricity supply networks
Capacitance	The ability of a system to store an electric charge
Covid-19	Coronavirus disease newly discovered in 2019
CSIRO	The Commonwealth Scientific and Industrial Research Organisation – an Australian Government research agency
CT	Current Transformer – a device used to reduce or multiply alternating current
DFA	Distribution Feeder Automation – a network reliability scheme implemented by AusNet Services
EDC	Electricity Distribution Code – a code that regulates distributing and connecting electricity to customers
Electric Current	Current – a flow of electric charge in a circuit
ESV	Energy Safe Victoria – Victoria's energy safety regulator
Fault	An abnormal electric current which bypasses normal operation
GFN	Ground Fault Neutraliser – a REFCL product manufactured by Swedish Neutral AB
Harmonic	A voltage or current at a multiple of 50Hz
HV	High Voltage – considered to be a voltage less than 66,000 and greater than 22,000 on electricity distribution networks
Impedance	The measure of effective resistance of an electric circuit or component to alternating current
kV	Kilo-Volt – 1,000 volts

LV	Low Voltage – considered to be a voltage less than 22,000 on electricity distribution networks
NER	Neutral Earthing Resistor – a non-REFCL network earthing approach used in Victoria
Network Damping	The measure of resistive losses in a polyphase network
Network Dissymmetry	The imbalance of capacitance to earth from each of the three phases in a polyphase network
Ohm	The unit of measurement of electrical resistance (ratio of voltage to current)
PAL	Powercor – an electricity distributor in Victoria
Partial discharge	An electrical discharge that connects small portions of insulation between two conductors
PBSP	Powerline Bushfire Safety Program – a powerline safety project initiated by the Victorian Government
Polyphase network	A network that distributes alternating electrical power consisting of three lines with voltages equally displaced by an equal angle
PSC	Power System Consultants Australia
RCC confirmation	A function of the GFN to test for a sustained earth fault
RCC, inverter	Residual Current Compensator – a REFCL component used in the GFN
REFCL	Rapid Earth Fault Current Limiter – a technology that quickly limits earth fault current
REFCL Program	A deployment program to install REFCL technology on 45 nominated electricity distribution networks in Victoria
Regulations	The Electricity (Bushfire Mitigation) Regulations (2016 amendment)
Required Capacity	Enhanced fault detection and suppression standard prescribed in the Electricity Safety (Bushfire Mitigation) Regulations (2016 amendment)
Resonant earthed	An electrical network with an Arc Suppression Coil connected to the neutral point of a zone substation power transformer
RIS	Regulatory Impact Statement – a process to move towards a best practice in regulatory design and implementation
RMS, rms	Root Mean Square – an average of instantaneous values
SEFM	Station Earth Fault Management – a device to manage earth fault protection schemes
Swedish Neutral	The manufacturer of the GFN, a REFCL technology
SWER	Single Wire Earth Return – a single wire distribution line
TFB	Total Fire Ban – a fire danger rating declared by Country Fire Authorities
THD	Total Harmonic Distortion – a measure of harmonic distortion present in a signal
Trench Group	A manufacturer of REFCL technology
Volt, V	Voltage – the unit to measure of the electric potential difference between two points
VT	Voltage Transformer – a device used to reduce or multiply alternating voltage
Zone substation	A station which converts incoming sub-transmission voltages to high voltage for distribution

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