Rapid Earth Fault Current Limiter (REFCL) Program

Network Balancing Strategy

Document Details	
Document Number:	REF 20-06
Version number:	2
Status:	Approved
Approver:	Jon Bernardo
Date of approval	19/04/2018

REVISION HISTORY

Issue Number	Date	Description	Author
1	29/03/2017	First Issue	J Bernardo A Walsh
2	19/04/2018	Second Issue	A Ziusudras

1 PURPOSE AND BACKGOUND

1.1 Purpose

The purpose of this supporting document is to explain AusNet Services' strategy in relation capacitive balancing 22kV networks affected by the installation of the Rapid Earth Fault Current Limiter (REFCL) installation program.

REFCLs are to be installed on AusNet Services' network in response to new bushfire mitigation regulations. Capacitive Network Balancing work is one of 5 work streams that comprise the REFCL installation program.

This category of work involves network modelling and the planned installation of new assets or rearrangement of existing assets required to ensure REFCL operation is optimised.

1.2 Background

AusNet Services' network operates in a unique geographical location, which is exposed to extreme bushfire risk. These conditions warrant significant investment to mitigate the bushfire risk.

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

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

The REFCL installation program will be managed in three Tranches. This network balancing strategy is expected to remain valid for all 3 Tranches however any changes to the strategy as a result of REFCL Program deployment learnings will be captured as a revision to this document.

The capacitive balancing of 22kV networks falls within the scope of work that we refer to as 'balancing works'. This category of work involves balancing each 'automated switching zone' where an automated switching zone is a feeder section delineated by Automatic Circuit Reclosers (ACRs), sectionalisers and/or circuit breakers. Balancing switching zones involves a combination of works including, phase transpositions, adding balancing capacitors and adding a third phase conductor to balance each section. A combination of this work involving the least cost for each switching zone will be undertaken.

As a consequence of the REFCL Program, the above works will be required on the REFCL protected network including transfer feeders that form part of the Distributed Feeder Automation (DFA) scheme.

1.3 Strategy objective

The objective of our network capacitive balancing strategy is to:

- describe the issues associated with the operation of a REFCL in a non capacitively balanced network;
- ensure current reliability performance is not permanently degraded following REFCL installation; and

- demonstrate that a prudent and efficient approach has been taken to the capacitive balancing of each automatic switchable section including transfer feeders as part of DFA scheme affected by the REFCL installation program.

2 Investment need

The Electricity Safety (Bushfire Mitigation) Amendment Regulations (2016) specify the voltage reduction required on a polyphase line when a phase-to-ground fault occurs, and the fault current levels that must be achieved. These specifications can only be met where the network is capacitive balanced to a level where network leakage current is below 0.1 (A). In addition, the more balanced the network is, the less likely the REFCL will maloperate for a non-fault condition, maintaining current reliability performance.

The need for this 'capacitive balancing' investment was highlighted in the REFCL trials:

> *"When an earth fault occurs on a resonant earthed network, the fault current falls to a low level made up of three components:*
>
> - *Resistive leakage current from the network to earth – the sum of all the tiny currents across the surfaces of tens or hundreds of thousands of insulators, plus current due to energy lost in cable insulation and in the iron core of the REFCL coil itself.*
> - *Current due to mismatch in the tuning of the REFCL coil to the network. REFCL designers take pains to ensure tuning is accurate to within an amp or two.*
> - *Current due to imbalance in the capacitance to ground in each of the three phases of the network. This is under the control of the network owner.*
>
> *Capacitive imbalance has some potential negative effects on REFCL performance:*
>
> 1. *It increases residual current, i.e. ground fire risk.*
> 2. *It increases the standing level of neutral voltage, i.e. it constrains fault detection sensitivity."*
>
> *In Victoria, long single phase (two-wire) spurs teed off three-phase lines can create significant capacitive imbalance. As fire risk reduction relies on low residual fault current, capacitive imbalance can pose a risk to fire safety and so must be managed*[1]*"*

A secondary driver of the need for a capacitively balanced network is to maintain network reliability. AusNet Services current DFA system can only operate successfully in conjunction with a REFCL where each automated switching zone is balanced.

The volume of balancing work in the REFCL program varies between zone substations.

3 Options analysis and preferred approach

The installation of REFCLs on the existing network requires the establishment of cost effective methods to establish and maintain network capacitive balance to achieve compliance with the Regulations. As already noted, network balance is essential if the REFCL technology is to operate as intended. As switching takes place immediately after a fault, capacitive balance is required in all possible network configurations for the REFCL to operate as intended.

The network is continually subject to asset augmentation, replacement and operational switching, which creates challenges for network balancing. It is noted that the Regulations set

[1] Dr Anthony Marxsen, REFCL Trial: Ignition Tests, Marxsen Consulting Pty Ltd, Monday 4 August 2014, page 95.

out a standard for fault current detection of 0.5 Amperes. In order to achieve this standard with current REFCL technology, the standing neutral voltage must be minimised as much as practicably possible, resulting in a permissible leakage current of less than 0.1 Amperes. This is no small challenge for any size network, as the Kilmore South (KMS) test configuration proved. Maintaining network balancing within these limits is expected to be difficult and labour intensive.

The proposed approach to balance REFCL protected feeders by switchable sections involves a combination of:

- Performing single-phase spur and distribution substation phase transpositions (e.g. where a network section may have more connections to the Red phase in comparison to the Blue phase a transposition can be made converting a Red and White connected spur or asset to the White and Blue phases);
- Installing balancing capacitor bank at the beginning of single phase spur sections;
- Installing LV balancing capacitor banks on the three-phase back bone; *and*
- In a small number of cases adding a third conductor to the beginning of a single-phase spur section (practical for cable) and converting that cabled section to three-phase.

Before determining our preferred approach to network balancing, we considered 3 alternative approaches, informed by our first REFCL experience at Woori Yallock installation.

1. Balance REFCL protected networks (each individual automatic switching zone) with a combination of phase transpositions, adding single and three phase capacitors, and installing third phase conductor (in small amounts) to balance each switchable section (our preferred option, as described above).
2. Same as Option 1, but not using three phase capacitors and installing greater amounts of third phase conductor to balance each section. This was the approach used at Woori Yallock originally, and it aligns with international practices.
3. Eliminate single phase network by addition of a third phase conductor.

In developing these options, AusNet Services considered non-network options and substitution possibilities between operating and capital expenditure. In relation to network balancing, there were no identified non-network options. As explained below, Option 3 provides an increased operating expenditure compared to Options 1 and 2, and therefore presents an opportunity to substitute operating and capital expenditure.

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

Table 1: Options evaluated

Option	Advantages	Disadvantages

Option	Advantages	Disadvantages
1. Balance REFCL protected networks with a combination of methods, minimising installation of the third phase by installing three phase capacitive balancing units.	Reduces volume of work required, minimises customer outages and disruption. Three phase balancing units have been proven to effectively reduce capacitive to ground imbalance. Ensures cost efficiency. Cost estimates can be found in each zone substation planning report.	Three phase balancing units introduce another technology risk to the REFCL program.
2. Balance REFCL protected networks with a combination of methods, not using three phase capacitive balancing units.	Reduced requirement to monitor and maintain new equipment to ensure network stays within balancing targets.	Customers potentially impacted for longer duration by running third phase works. Some poles and spans will require redesign to accommodate the additional third phase. Public safety risk due to bare open wire powerlines is increased with addition of third phase. Requirements of the Regulations not fully achieved. Caps are required to balance voltages which cannot be done by adding third phase. Greater cost than Option 1
3. Balance REFCL protected networks by installing an additional third phase on all single phase sections.	No requirement to monitor and maintain new equipment to ensure network stays within balancing targets.	Costs are significantly higher because of the extent of single phase network on the REFCL networks. Time consuming and labour intensive. Public safety risk increase from additional bare open wire powerlines being installed. Requirements of the Regulations not fully achieved. Caps are required to balance voltages which cannot be done by adding third phase. Greater cost than Option 1

Option 1 is the preferred option as it has:

- Lower cost than Options 2 and 3;
- Reduced public safety risk when compared to Option 2 and 3; and
- Meets the objective of efficiently reducing leakage current in a dynamic network.

3.1 Preferred Option Risks

The key risk associated with the network balancing works is the ability to accurately scope and install the works in a timely manner. The scoping of works require data of the network that traditionally hasn't been captured accurately as the importance for low impedance networks is mainly driven by load with network capacitance planning neglected. This may lead to additional transpositions or installations of assets i.e. LV balancing units or third phase conductors, all leading to increased cost.

4 Efficient and prudent program delivery

The following high level delivery plan is to:

1. Determine leakage current (seen at zone substation) of REFCL protected feeders and automated switching zones;
2. Identify and complete phase transpositions along the feeder such that leakage current is within capacity of the LV balancing capacitor units;
3. Unbound three phase cable or install small sections of third phase conductor where required;
4. Install LV balancing capacitor units to minimise leakage current; *and*
5. Ensure leakage current is maintained once REFCL is in service, by removal of some fuses from the network and phase nameplates are accurate at each automatic switchable section.

This sequence of activities ensures that the more expensive activity (installing capacitors) is only undertaken after the less expensive phase transpositions are complete thereby minimising the number of capacitors installed.

Ensuring delivery efficiency of the above plan relies on integration of balancing works with other work activities on the network such as business as usual maintenance, safety programs and supplementary REFCL line works.

4.1 Risk management

The risks associated with delivery of the program of network balancing are shown in the table below.

Risk	What could occur	Actions & controls

Risk	What could occur	Actions & controls
Interference / clashes with other project(s) and project scope creep.	Delivery delays leading to non-compliance with Bushfire Mitigation Regulations and the approved Bushfire Mitigation Plan. Down time for construction crews	Continual engagement with Network Planning Teams and delivery partners. Network Programs constant review of Portfolio projects. Dedicated Program Sponsor Team established.
Delivery delays in meeting the REFCL regulatory obligation	Delivery delays leading to non-compliance with Bushfire Mitigation Regulations and the approved Bushfire Mitigation Plan.	Monthly reporting of the progress of the project from delivery partners through to the Program Team / Steering Committee and Energy Safe Victoria. Regular updates of Asset Management System enabling progress to be tracked real-time. Well planned schedule of works. Early engagement with Control Energy Operations Team (CEOT), delivery partners and field personnel to ensure resourcing availability.
REFCL networks cannot be capacitively balanced.	Accurate network balance is essential if the performance criteria are to be met. To date there is limited experience that a large multi-feeder network can be accurately balanced and validated.	Extensive survey, design and modelling work is required. Works must ensure all material capacitive imbalances are accounted for on the REFCL networks.

4.2 Procurement

Network balancing works are to be completed utilising standard stock items. These items have and will be procured utilising AusNet Services' standard procurement and governance processes which include competitive tendering to ensure the cost per unit is efficient.

4.3 Works delivery

The scope of balancing work varies significantly for each zone substation however will be largely dependent on the following three items:

- The number of existing automatic switchable sections served by the zone substation. Automatic switchable sections, a feeder section delineated by an Automatic Circuit Recloser (ACR), sectionaliser and/or circuit breaker, are used to ensure customer outages are minimised in the event of a fault occurring on the network. Typically heavily vegetated and populated areas have a greater number of automatic switchable sections.
- Number of 22kV feeders emanating from the zone substation and total route length of the 22kV network at each respective site; and

- Number of transfer feeders from normally non-REFCL protected feeders to REFCL protected zone substations. This increases the amount of 22kV network requiring to be balanced.

The network balancing field work will mainly be constructed using established external delivery partner relationships. Internal resources may be utilised for integration opportunities with other required works on 22kV feeders where appropriate.

Key steps involved to deliver this work include:

Design works:

- Complete patrol of 22kV feeders confirming accuracy of nameplate and AMS (Asset Management System) data. Survey will also include terminations of existing single phase cable equipment.
- Identification of all 22kV single phase sections of network. Phase identification tools will be utilised for this activity to ensure correct phasing is recognised.
- Updating phase data information back into AMS.
- Network modelling of the network capacitive imbalance for each automatic switchable section.
- Real-time validation of the capacitive network modelling. Achieved by amassing the out of balance in each section whilst the network is switched. Current transformers and earth fault relays will be required to be installed in some cases ahead of the zone substation works to ensure accurate modelling is achieved.
- Confirmation of the number of sites and locations where phase transpositions, single and three phase capacitors, unbonding of third phases and phase plate adjustments.

Physical works – achieve required network balancing:

- In a minority of cases, install spans of third phase at the beginning of single phase spurs which involves re-conductoring up to the value where it is economically favourable in comparison to installing a LV balancing capacitor unit.
- Historically where cable has been used for single phase sections the unused or 3rd phase is bonded to another phase. This poses an issue as the paralleling of conductor cores results in doubling the effective capacitance of the conductor phase. Removal of the bonded phases at these installations needs to be completed.
- Transpositions or phase rotations will be required at locations where leakage current for the section is minimal. This can occur at the beginning of single phase spur sections or at pole top transformer connections and has been highlighted in the RIS as the solution to balance the capacitance of the network. Correction of field phase plates and adding a verified label to all ACRs and sectionalisers will accompany this work.
- Single phase or three phase LV balancing capacitor units will be installed where the level of out of balance is too great for a phase transposition to mitigate. The LV balancing capacitor units require a bespoke transformer to facilitate the application. Although the use of balancing capacitors was not considered in the Regulatory Impact Statement, it has since been proven to be a cost effective and efficient way of mitigating the out of balance capacitance.

Inherent works:

- In order to complete the design and physical works, various Asset Management System (AMS) tools need to be modified to enable efficient design and construction of the network balancing scope. Improving existing AMS tools such DOMS, SDME, Sincal, SCADA and SAP allow designers to leverage from existing network data information to highlight and calculate areas of work for a feeder. For example, high voltage aerial bundle cable or single phase sections can be highlighted complete with phasing information and route length in kilometers. This will assist in estimating the present out of balance and consequently determine the engineering solution for that area. Improvements to these tools will also feed into protection reviews to identify opportunities where fuses can be removed or replaced.

- Other inherent works including the development of a balancing capacitor solution and purchase of phase identification tools have already been completed and are not forecast to involve additional expenditure in Tranches 2 or 3.

4.4 Program costs and benchmarking

The Network Balancing Strategy preferred option has been costed in accordance with our standard costing methodology, as detailed in the supporting document: Cost Estimating, program delivery and unit rates.

The costs detailed below include:

- Site visits;
- Data validation;
- Design of network balancing scope i.e. phase transpositions, single and three phase LV balancing capacitor units;
- Works and network contingency planning and governance activities;
- Construction works;
- Testing, communications and commissioning;
- Project management; and
- Auditing.

It must be reiterated that the significant amount of network balancing works is driven by the need to reduce leakage current to minimum levels, which is directly proportional to the network size. This exercise leads to a lower standing neutral voltage i.e. dissymmetry which impacts the ability of the REFCL to reliably detect the demanding performance criteria as explained in REF 30-06 REFCL Program – Arc Suppression Coil sizing policy document.

A summary of the capital expenditure requirements for each REFCL installation will be included in the respective zone substation REFCL Planning Report.

4.5 Program governance

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

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

- Clear accountabilities, reporting and robust risk and issue management;
- Sustainable, long term, reliable, economical and workable whole of life designs;
- Delivery as per agreed timelines without compromising reliability and other service standards;
- Integration where possible with the rest of the AusNet Services work program;

- Compliance with required obligations;
- Strong relationships with all stakeholders in order to successfully manage change;
- Development of internal capability in order to facilitate the transition to business as usual; and
- Use of business as usual processes and resources where possible.

5 Concluding comments

This document has explained that:

- The proposed scope of balancing work is the lowest cost and lowest risk option for addressing the specific issues on REFCL protected networks;
- We have considered non-network options and the substitution possibilities between capital and operating expenditure.
- Our network balancing work is consistent with our approved strategy and relevant policies;
- We have employed our standard approach to network balancing cost estimation;
- The key assumptions underpinning our forecasts are reasonable;
- We have identified the key risks in relation to network balancing works and taken appropriate risk mitigation measures; and
- Our projected costs (refer to relevant Planning reports) are consistent with the estimated average unit costs in the RIS

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

For these reasons, we regard the forecast expenditure for our network balancing approach as prudent and efficient, in accordance with the Rules requirements relating to contingent projects.