Line Surge Arresters

AMS – Electricity Distribution Network

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Disclaimer

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Table of Contents

1 Executive Summary

This document is part of the suite of Asset Management Strategies relating to AusNet Services' electricity distribution network. The purpose of this strategy is to outline the inspection, maintenance, replacement and monitoring activities identified for economic life cycle management of line surge arresters in AusNet Services' Victorian electricity distribution network.

This strategy is focused on 140,000 line surge arresters protecting distribution substations; automatic circuit reclosers (ACRs) and gas-insulated switches; line voltage regulators; capacitors; and underground cable termination poles.

Line surge arresters have been installed on new medium voltage installations since the mid-1970s to limit electricity supply outages. After 1980, considerable numbers of surge arresters were replaced in order to reduce the risk of fire ignition from the network. Hence, the existing population of surge arresters is relatively young, with a mean service age of 21 years.

Since 2017, Rapid Earth Fault Current Limiter (REFCL) has been the major driver for the line surge arresters' replacement. Following the installation of REFCL technology, line surge arresters must cater for elevated phase to ground voltages up to 24.2kV (i.e. 22kV plus 10%). Line surge arresters that cannot withstand elevated voltages will need to be replaced.

A high-intensity lightning strike near a surge arrester can generate surge voltages and currents in excess of the ratings of the surge arrester. In some cases, the surge arrester cannot dissipate the energy of the lightning and will fail due to a combination of excessive internal pressures and arcing damage to the housing exterior. Sustained interruptions to electricity supplies, fire ignition and collateral damage usually accompany these failures. From the past 7 years' performance, a customer might experience loss of supply due to unplanned interruptions initiated by lightning in an average of 0.01 minutes per event per year.

Condition assessment shows that about 73% of line surge arresters are in "Very Good" (C1) condition mainly due to the REFCL driven surge arrester replacement project. Approximately 16% are nominally in a "Very Poor" (C5) condition consistent with the significant number of gapped silicon carbide line surge arresters with porcelain housings.

Risk analysis of line surge arresters, using quantified consequence/criticality shows that approximately 4% of the condition 4 and 5 line surge arresters are in the criticality 4 and 5 categories. In order to manage the risk "as far as practicable" as per the Electricity Safety Act, it is recommended to proactively replace line surge arresters located in the high consequence effect and worst condition regions. The summary of key asset strategies is listed below.

1.1 Asset Strategies

1.1.1 New Assets

- Install metal oxide surge arresters with polymeric housings in accordance with AusNet Services' published standards.
- Install animal proofing on Surge Arresters (Refer to *ETB 005-2018 Technical Bulletin- Animal Proofing Surge Arresters using Electrostatic Animal Guards*)

1.1.2 Inspection

- Inspect line surge arresters in accordance with Asset Inspection Manual 30-4111

1.1.3 Replacement

- Review and replace surge arresters in REFCL areas in accordance to AusNet Services' guideline[6]
- Progressively replace Condition 4 and 5 surge arresters in high consequence effect area by 2025
- Reactively replace defective or faulty line surge arrester

2 Introduction

2.1 Purpose

The purpose of this document is to outline the inspection, maintenance, replacement and monitoring activities identified for economic life cycle management of line surge arresters in AusNet Services' Victorian electricity distribution network. This document intends to be used to inform asset management decisions and communicate the basis for activities

In addition, this document forms part of our Asset Management System for compliance with relevant standards and regulatory requirements. This document demonstrates responsible asset management practices by outlining economically justified outcomes.

2.2 Scope

This Asset Management Strategy applies to all line surge arresters associated with the AusNet Services electricity distribution network that operate at 22 kV, 12.7kV, 11 kV and 6.6 kV.

Surge arresters in substations are not covered in this document. Asset management strategies for surge arresters in zone substations are described in *AMS 20-77 "Surge Arresters in Zone Substations".*

2.3 Asset Management Objectives

As stated in *AMS 01-01 Asset Management System Overview*, the high-level asset management objectives are:

- Comply with legal and contractual obligations;
- Maintain safety;
- Be future ready;
- Maintain network performance at the lowest sustainable cost; and
- Meet customer needs.

As stated in *AMS 20-01 Electricity Distribution Network Asset Management Strategy*, the electricity distribution network objectives are:

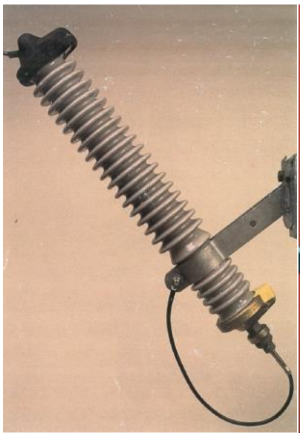
- Improve efficiency of network investments;
- Maintain long-term network reliability;
- Implement REFCL's within prescribed timeframes;
- Reduce risks in highest bushfire risk areas;
- Achieve top quartile operational efficiency; and
- Prepare for changing network usage.

3 Asset Description

3.1 Asset Function

Line surge arresters are installed on AusNet Services electricity distribution network to protect distribution apparatus connected to the overhead network from impulse, over-voltage damage; typically, due to lightning strikes and switching surges.

Figure 1 below shows an old technology porcelain housed surge arrester (on the left) and Figure 2 shows the polymer housed surge arresters (on the right)



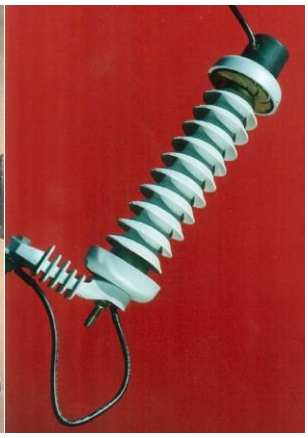


Figure 1 - [C.I.C] housed surge arrester Figure 2 –[C.I.C] housed surge arrester

A polymer housed surge arrester (marked in red circle) fitted to an isolating transformer is shown below:

Figure 3 - Polymer housed surge arrester fitted to an isolating transformer

3.2 Asset Population

AusNet Services' medium-voltage electricity distribution network in Victoria has approximately 140,000 surge arresters protecting approximately 61,000 distribution substations, almost 4,000 ACRs and gas-insulated switches, 140 line voltage regulators, 80 pole-mounted capacitors and more than 1,200 underground cable termination poles[1].

As part of the standard design and specification, surge arresters have been installed on new medium voltage installations since the mid-1970s to limit electricity supply outages. After 1980, considerable numbers of surge arresters were replaced in order to reduce the risk of fire ignition from the network. Hence, the existing population of surge arresters is relatively young, with a mean service age of 23 years.

Prior to the early 1980s, surge arresters contained gapped silicon carbide blocks housed in a porcelain insulating shell. From the early 1980s, surge arresters contained gapless metal oxide-type blocks and in the late 1990s porcelain housings gave way to polymeric housings.

Modern metal oxide surge arresters offer considerably better over-voltage protection in comparison to silicon carbide units. There are no internal spark gaps in metal oxide type and they react faster to over-voltage transients.

In the late 1990s the technical specifications for surge arresters were improved. The nominal discharge current was increased from 5,000A to 10,000A, and the maximum continuous operating voltage for surge arresters installed on 22kV circuits was increased to 18kV to provide an adequate operating margin on circuits with earth fault limitation provided by neutral earthing resistors.

Since 2017, Rapid Earth Fault Current Limiter (REFCL) has been the major driver for the line surge arresters' replacement[2]. AusNet Services' line surge arresters are designed for phase to ground voltages up to 19.5kV. Following the installation of REFCL technology (Section 4.1), they must now cater for elevated phase to ground voltages up to 24.2kV (i.e. 22kV plus 10%). Line surge arresters that cannot withstand elevated voltages must be replaced.

Modern designs have a polymer housing moulded directly to the semi-conducting blocks; as such there are no seals, and moisture ingress – previously a common failure mode – is avoided. There is also less trapped air volume for rapid pressure build-up during a failure, and as such, the failure mode is less harmful.

There are approximately 30 different types of surge arresters employed on medium-voltage installations, as illustrated in Table 1.

3.2.1 Population by Type

Table 1 - Surge Arresters by Type

Surge Arrester Type	Manufacturer	% of Fleet
A	C.I.C	11.6%
B		2.4%
C		<1%
D		<1%

[1] 2017 AusNet Services (Distribution) Category Analysis

[2] REF 20-07 Hardening Strategy-Lines

E	C.I.C	<1%
F		<1%
G		<1%
H		<1%
I		<1%
J		<1%
K		<1%
L		<1%
M		<1%
N		3.5%
O		<1%
Q		3.8%
Q		<1%
R		<1%
S		<1%
T		<1%
V		<1%
W		<1%
X		54.2%
Y		7.5%
SIEM-A		6.3%
ABB-A		<1%
CLAH		<1%
ABB-K		<1%
HUB-C		1.5%
COOP-27		3.6%
Unknown		2.5%

Approximately 54% of surge arresters are of [C.I.C] type with metal oxide semi-conducting blocks and a polymeric housing. The next most common surge arrester type forming approximately 12% of the total fleet is a porcelain housed silicon carbide unit manufactured by [C.I.C].

These two types comprise more than 66% of surge arresters in the fleet. About 9 types have fewer than 100 surge arresters in service as they are being progressively replaced by newer polymeric hosing surge arresters.

3.2.2 Population by Manufacturer

Surge arresters in the fleet are from six manufacturers. As illustrated in Figure 4 more than 85% of the surge arresters are from [C.I.C] manufacturers.

C.I.C

3.2.3 Population by Housing Material

Since 2009, the proportion of polymeric housing surge arresters has increased from 32% to 81% of the population.

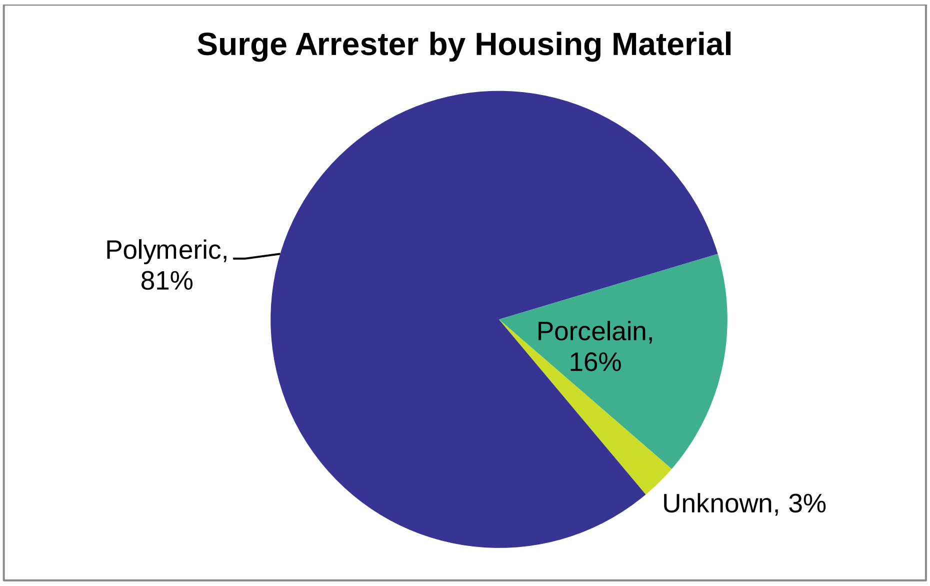


Figure 4 – Surge Arresters by Housing Material

3.3 Asset Age Profile

Surge arresters that are currently in service have an average age of 21 years with the standard deviation of 17 years. Majority of the [C.I.C] have been in service since 1999, which contribute to 66% of the overall surge arresters' population.

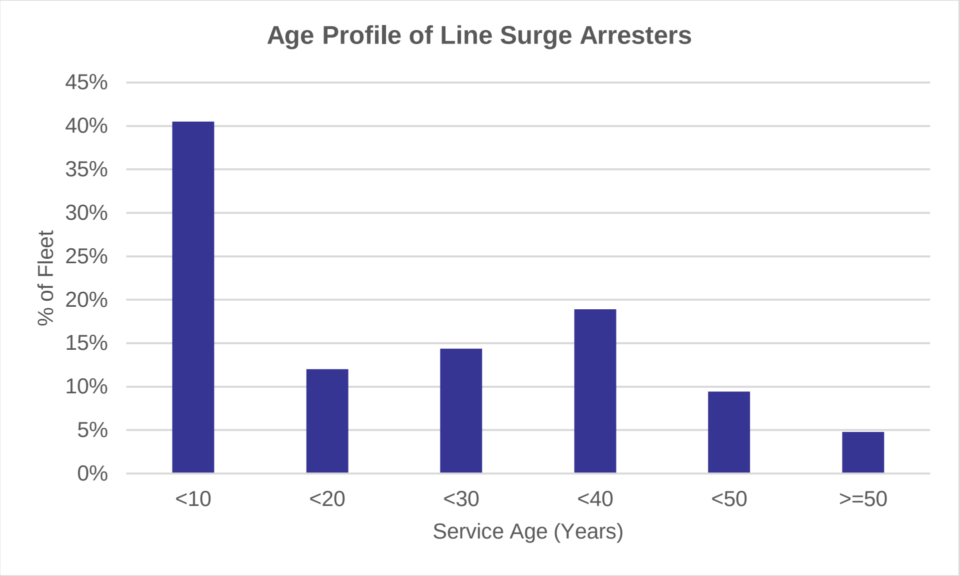


Figure 5 - Surge Arresters Age Profile[1]

3.4 Asset Condition

To provide a consistent assessment of the condition of the whole asset group, a common condition scoring methodology has been developed. This methodology uses the known condition details of each asset and grades that asset against common asset condition criteria.

There are five different condition scores that have been applied to each line surge arresters, ranging from "Very good" (C1) to "Very Poor" (C5). Table 2 describes the attributes, which determine the condition score rating.

Table 2 - Condition Scoring Methodology

Condition Scoring Methodology			
Condition Score	**Condition Description**	**Summary of Condition Score**	**Remaining Life**
C1	Very Good	• New condition • Incorporates the new metal oxide designs with polymer housings • Are in an acceptable visual condition with no signs of corrosion, tracking or damage • Have no historical problems	95%
C2	Good	• Incorporates the new metal oxide designs with polymer housings • Are in an acceptable visual condition • Have no or very little historical problems	70%

C3	Average	• Incorporates metal oxide designs with polymer housings. • Are in an acceptable visual condition , • Some historical problems	60%
C4	Poor	• Incorporates silicon carbide designs with porcelain housings and some metal oxide designs with polymer housings • Are beginning to develop signs of deterioration on the insulator material, the housing, venting duct covers and/or diaphragm	45%
C5	Very Poor	• Are typically of the old technology type that incorporates silicon carbide designs with porcelain housings • The visual condition of the surge arrester is unacceptable as major signs of deterioration on the insulator material, seals or caps are visible or tracking and mechanical damage to the housing • Advanced performance deterioration	25%

For further detailed information regarding the condition assessment framework, specific issues, conditional maintenance activities and discussion of fails, refer *to AHR 20-67 – Line Surge Arrester Asset Health Report*.

3.4.1 Line Surge Arrester Condition Summary

Condition summary for line surge arrester is shown in Figure 6:

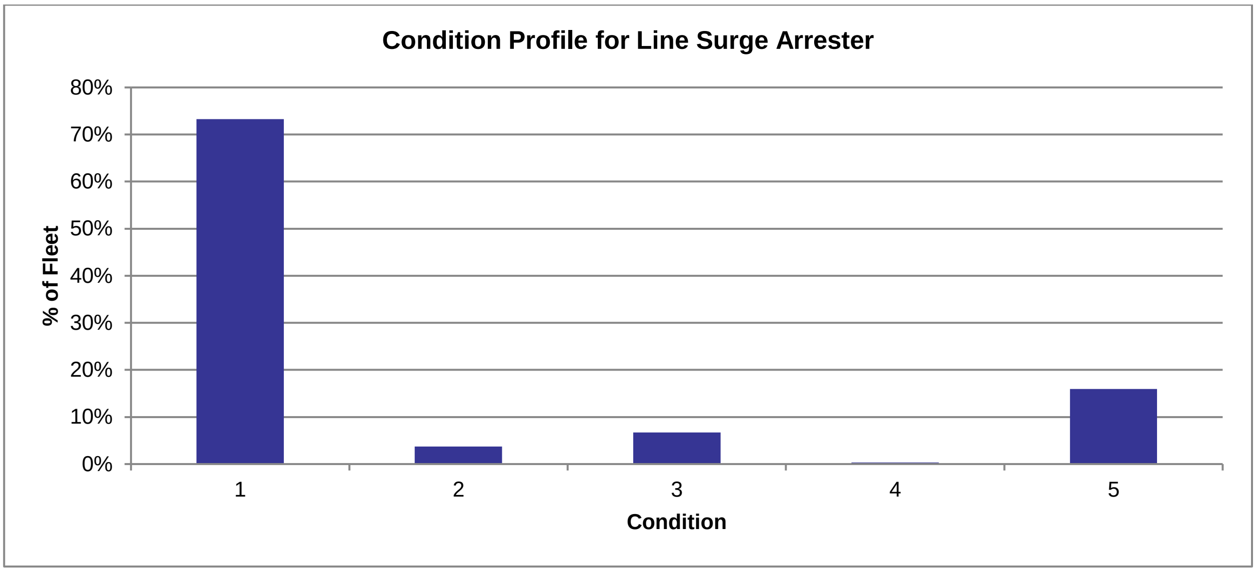


Figure 6 - Condition Profile for Line Surge Arrester

Approximately 16% of line surge arresters are in “Very Poor” (C5) condition consistent with the significant number of gapped silicon carbide line surge arresters with porcelain housings, still in service. About 73% of surge arresters are in “Very Good” (C1) condition mainly due to the REFCL driven surge arrester replacement project outlined in Section 4.1.

3.5 Asset Criticality

The consequence of line surge arresters failure is allocated into five criticality bands based on their economic impact as the result of a failure. These asset criticality or consequence impacts are irrespective of the likelihood of the actual failure.

The economic impact consists of the summation of three components:

- Bushfire start impact
- Health and safety impact
- Value of unserved energy

3.5.1 Bushfire Starts

The risk associated with a bushfire is calculated by applying the probability of fire ignition, probability of unfavourable weather conditions, expected house loss consequence and house loss value. Data has been sourced from the Victorian Bushfires Royal Commission findings, Government departments, Bureau of Meteorology and CSIRO.

Since 2006, there have been 20 Surge Arrester failures that have led to fire ignitions. 60% of these failures caused ground fires.

3.5.2 Health and Safety Risk

Health and Safety risk related, such as catastrophic failure risk, to the possibility that a safety consequence may occur as a result of a Surge Arrester failure.

3.5.3 Unserved Energy

Values of expected unserved energy were calculated by using the value of customer reliability (VCR) and the expected outage time. Mean time to restore (MTTR) is used to estimate the expected outage time. The approach taken is consistent with AEMO's energy forecasting approach as detailed in paper by AEMO and in AusNet Services Distribution Annual Planning Report (DARP)[3]

3.5.4 Overall Criticality

The five criticality bands are tabulated below:

Table 3 - Criticality Band for Line Surge Arrester

Criticality	Definition

[3] Distribution Annual Planning Report – AusNet Services 2018-2022

Band	
1 – Very Low	Potential consequence of asset failure in case of a network fault event is less than or equal to 1 times unit replacement cost (URC)
2 - Low	Potential consequence of asset failure in case of a network fault event is between 1 to 3 times URC
3 – Medium	Potential consequence of asset failure in case of a network fault event is between 3 to 10 times URC
4 – High	Potential consequence of asset failure in case of a network fault event is between 10 to 30 times URC
5 – Very High	Potential consequence of asset failure in case of a network fault event is greater than 30 times URC

As the result of the criticality analysis, approximately 4% of the condition 4 and 5 line surge arresters are in the criticality 4 and 5 category. Figure 7 shows the criticality for all line surge arresters.

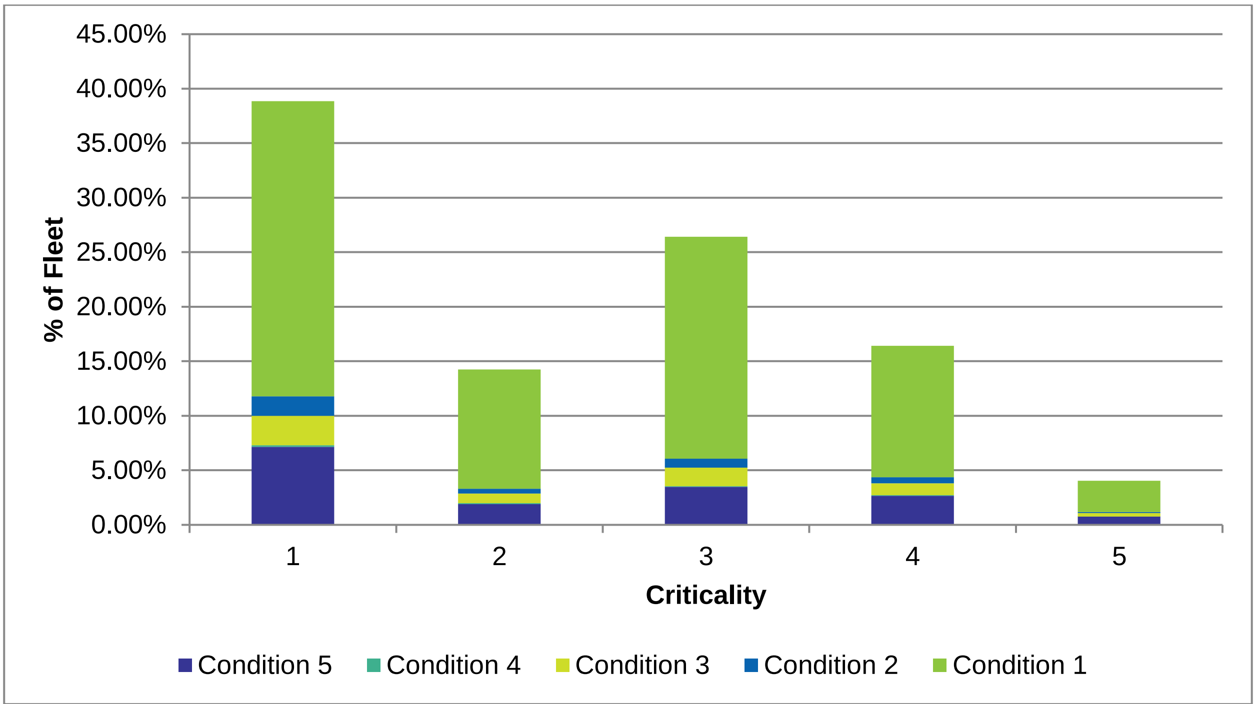


Figure 7 - Criticality for Line Surge Arrester

3.6 Asset Performance

3.6.1 Reactive Maintenance

Approximately 876 incidents related to Surge Arresters were recorded in PowerOn Fusion Distribution and Outage Management System (DOMS) from 2011 to 2017. The causes of the failure are shown in Figure 8.

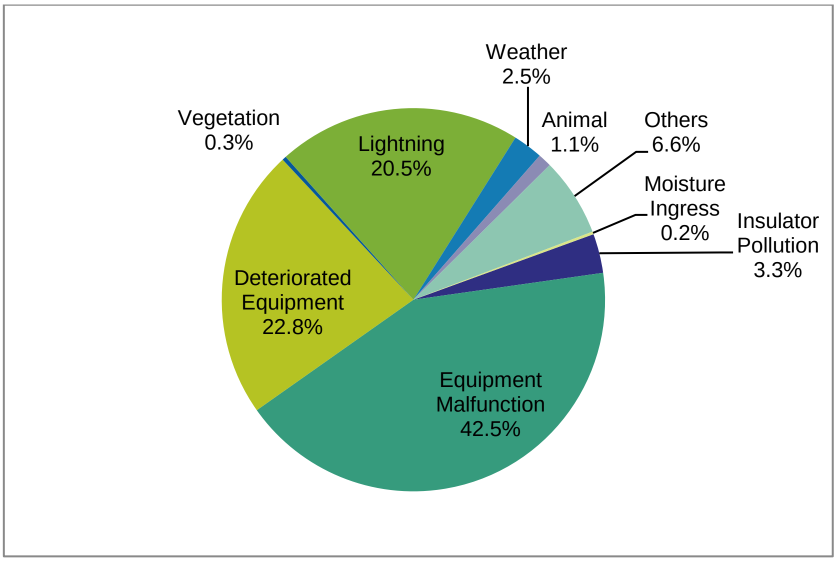


Figure 8 - Cause of Surge Arrester Related Failures

3.6.2 Defect Work Orders

There were about 770 work orders raised from 2015 to 2017 due to problems found during inspections of poles and pole top assets, or any other site work recorded in the Enterprise Asset Management System –SAP.

88% of these work orders were related to missing surge arresters and the remaining 12% were due to unacceptable surge arresters installed in the network.

3.6.3 Fire Ignition

Since 2006, there have been 20 surge arrester failures that have caused fire ignitions. Twelve of these failure caused ground fires. Figure 9 shows the historical trend of fires related to surge arresters. There were no surge arresters related fires reported in FY17 and FY18.

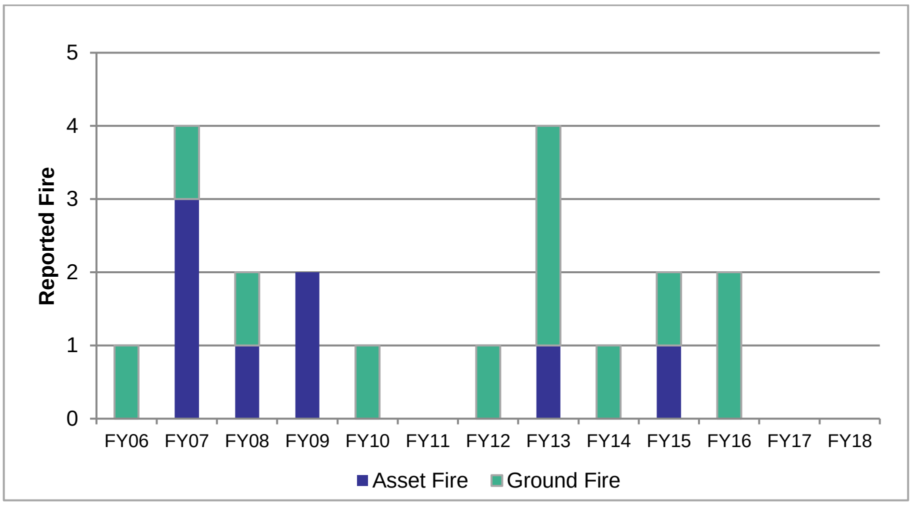


Figure 9 - Surge Arresters related fires

4 Other Issues

4.1 Rapid Earth Fault Current Limiter (REFCL)

The Victorian Government has mandated the rollout of Rapid Earth Fault Current Limiter (REFCL) installations across nominated zone substations in AusNet Services' network. Twenty-two zone substations and the associated 22kV feeders will be modified to allow for resonant earthing. Line hardening work is one of the five work streams that comprise the REFCL installation program. Details of the line hardening strategy can be found in REF 20-07[2].

Surge Arresters that are fitted in the REFCL protected network (high impedance) must be capable of sustaining the elevated voltages which occur on healthy phases in response to a phase to ground fault. Sustained over-voltages will be experienced regularly during REFCL operation. Surge arrester types that are unsuitable for withstanding REFCL voltage rise are identified in the Surge Arrester Replacement Functional Scope[4] document.

4.2 Inspection

Line surge arresters inspected as part of the routine pole inspection as per the Asset Inspection Manual 30-4111. Inspection includes visual assessment of surge arresters and recording any defects such as failed lead, broken lead, chipped porcelain or missing surge arresters and fittings. The standard maintenance guideline for Line Surge Arrester is detailed in SOP 70-03.

4.3 Installations and Replacement

All new distribution substations installed since 2003 have had fully insulated covers fitted and existing substations are being progressively retro-fitted in priority order.

There has been a mixture of maintenance strategies employed for surge arresters protecting pole-mounted assets over the last 20 years:

- The need to improve fire ignition performance after 1980s drove planned replacement strategies that focused on the introduction of surge arresters able to meet the fire ignition requirements of Australian Standard AS1307
- A replace-on-failure strategy has been employed for those surge arresters meeting AS 1307
- For the last decade, the replace-on-failure strategy has focused on maintaining over-voltage protection on three-phase installations.
- Line surge arresters' replacement due to REFCL requirement,

Historical installations/replacement volume can be found in the Electricity Network Works Program document[5].

[4] Project DD-0006633 REFCL Program Tranche 1: Surge Arrestor Replacement Functional Scope Issue 2

[5] Electricity Networks Works Program FY19-FY23

4.4 Failure Modes

Four modes of failure are common for medium-voltage surge arresters:

- Leakage currents trigger disconnection
- Seal failure allows moisture ingress
- External arcing fault
- Amplitude of lightning strike exceeds surge arrester ratings.

4.4.1 Leakage Currents Trigger Disconnection

The predominant failure mode for surge arresters arises toward the end of their effective life when the internal silicon carbide or metal oxide blocks allow the passage of power frequency leakage currents to flow through the earth leakage disconnect (ELD) device to earth.

Leakage currents trigger a pyrotechnic charge within the base of the surge arrester, generating high-pressure gasses to blow the earth lead clear of the lower end of the surge arrester. This action disconnects the surge arrester from its earth connection, rendering it inoperative. The surge arrester remains connected to the MV conductors. The new position of the ELD provides a signal for asset inspectors that the surge arrester is no longer operative.

Figure 10 - Operation of an Earth Leakage Disconnector

4.4.2 Seal Failure Allow Moisture Ingress

A common failure mode for silicon carbide surge arresters is the deterioration of the sealing medium between end caps and the housing allowing moisture ingress. The moisture is distributed between the outer face of the semi-conducting blocks and the inner face of the housing. Over time, the presence of moisture allows power frequency leakage currents to flow from the MV conductor to earth. These currents do not pass through the earth lead disconnect device but generate high-pressure steam between the blocks and the housing. This can rupture the surge arrester and may lead to an explosion.

In the early 1980s, it became evident that under certain circumstances some classes of porcelain surge arresters could explode and shatter releasing hot metal fragments. This failure mode causes particular risks because the failure violently propels hot semi-conducting blocks and porcelain shards from the surge arrester. This failure mode is usually accompanied by a sustained outage as upstream fuses, ACRs and CBs operate to interrupt power frequency follow-through currents. Fire ignition and collateral damage can result from failures of this type. To address this issue surge arresters were introduced in the network with explosion relief features and earth lead disconnect device, which automatically disconnects the surge arrester if power frequency current flows.

The polymeric housings moulded over the semi-conducting blocks of zinc oxide surge arresters can ignite under arcing faults, as illustrated in Figure 11. However, the absence of gaps between semi-conductive blocks and the polymeric housing greatly reduces the probability of moisture ingress and consequences associated with explosive failures.

Figure 11 - Failure of Polymeric Surge Arrester Housing

4.4.3 External Arching Fault

Surge arresters are installed close to the bushings and the earthed tank of transformers they are intended to protect. If the connections to the transformer are not fully insulated, birds or animals can bridge the energised conductor to earth.

The presence of a medium-voltage arc in close proximity to the transformer bushings can damage the housing of the surge arrester, the transformer bushings, the connections and any insulating covers. As with internal arcing faults, this mode of failure is accompanied by a sustained interruption to electricity supply as upstream protection operates to interrupt power frequency fault currents. Fire ignition and collateral damage can result from failures of this type.

4.4.4 Amplitude of Lightning Strike Exceeds Surge Arrester Ratings

A high-intensity lightning strike near a surge arrester can generate surge voltages and currents in excess of the ratings of the surge arrester. In some cases, the surge arrester cannot dissipate the energy of the lightning and will fail due to a combination of excessive internal pressures and arcing damage to the housing exterior. Sustained interruptions to electricity supplies, fire ignition and collateral damage usually accompany these failures.

Table 4 summarises the impact of lightning on the reliability of electricity supplies in eastern Victoria. In these events, surge arresters were not effective in preventing the effects due to lightning.

Table 4 - Reliability Events due to Lightning

Year	2011	2012	2013	2014	2015	2016	2017	Average
USAIDI (minutes)	14.10	6.25	6.88	20,50	21.04	7.88	12.04	12.67
Events	1406	959	783	1096	1254	768	745	1002
USAIDI per Event	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.01
UCAIDI (minutes)	102.10	53.31	68.62	129.84	137.10	79.72	113.90	97.80

There are about 1000 supply outages initiated by lightning each year. From the past 7 years' performance, a customer might experience loss of supply due to unplanned interruptions initiated by lightning in an average of 0.01 minutes per event per year. On average, the duration of an unplanned customer interruption is at about 98 minutes.

Based on 708,619 connected customers, the current Service Target Performance Incentive Scheme (STPIS) estimated on average, a lightning initiated outage has a value of $7,200.

5 Risk and Options Analysis

5.1 Overview

Line Surge Arresters are essentially maintenance-free device. If it is correctly installed, there is no maintenance during the life of a modern Surge Arrester, except for targeted retro-fitting of bird and animal insulating covers to reduce the incident of arcing faults over the surge arrester housing.

This section outlines the key risks presented by line surge arresters and discuss how these risks should be addressed.

5.2 Risks

The risk matrix, showing combination of condition and consequence, of Line Surge Arrester located in a non-REFCL area is tabulated in Table 5

Table 5 - Risk and Condition Matrix of Line Surge Arresters in non-REFCL region

		Condition – Line Surge Arresters in non-REFCL area					Quantity
		1	2	3	4	5	
Criticality Band	5	1574	53	174	11	480	2292
	4	9130	560	910	57	2366	13023
	3	16169	845	1606	86	3105	21811
	2	8603	353	815	71	1612	11454
	1	21832	1817	2298	230	6347	32524
	Quantity	57308	3628	5803	455	13910	81104

In Table 5, the greatest risk appears on the top right corner, whereas the lowest risks are in the bottom left corner.

5.3 Options

5.3.1 Proactive Replacement

Replacement forecast is derived from a semi-quantitative risk assessment method using a consequence/likelihood matrix. The consequence of a Line Surge Arrester malfunction is assigned with a consequence cost which is determined by the bushfire effect cost, value of unserved energy, health and safety cost.

The replacement cost is derived from historical financial records. The components of the unit replacement cost are the cost of equipment and labour to install the equipment. The labour component of the replacement cost includes the amount of time required to perform the corrective maintenance activity on a per hour basis.

In order to manage risk "as far as practicable" as per the Electricity Safety Act, it is recommended to address line surge arresters with the worst condition located in the highest consequence effect region shown in red in Table 5,

If a surge arrester is located in the REFCL region, it will be reviewed and subjected to replacement in the REFCL project[6].

Line surge arresters may also be replaced with other asset replacement works, for example. pole, switches, and distribution transformer replacement. SAP notification analysis shows that an estimated one-third of the Line Surge Arresters will be replaced due to the above reason.

As a result of the risk and options evaluation, it is estimated that 287 line surge arresters will be targeted for proactive replacement per annum during the EDPR period of 2022 to 2026.

5.3.2 Reactive Replacement

Historical fault analysis shows an estimated count of 348 line surge arresters were reactively replaced per year in non-REFCL areas.

5.3.3 Overall Replacement Forecast

Table 6 summarises the replacement forecast:

Table 6 - Replacement Forecast

Identifier	Justification	Contribution per Annum
Proactive Replacement	Probabilistic replacement based on Condition with high consequence effect cost	287
Reactive Replacement	Probabilistic replacement due to defect or fault	348
	Total Replacement	635

[6] REFCL Lines Surge Arrestor Functional Scope Issue 2

6 Asset Strategies

6.1 New Assets

- Install metal oxide surge arresters with polymeric housings in accordance with AusNet Services' published standards.
- Install animal proofing on Surge Arresters (Refer to *ETB 005-2018 Technical Bulletin- Animal Proofing Surge Arresters using Electrostatic Animal Guards*)

6.2 Inspection

- Inspect line surge arresters in accordance with Asset Inspection Manual 30-4111

6.3 Replacement

- Review and replace surge arresters in REFCL areas in accordance to AusNet Services' guideline[6]
- Progressively replace Condition 4 and 5 surge arresters in high consequence effect area by 2025
- Reactively replace defective or faulty line surge arrester