MV Fuse Switch Disconnectors

AMS – Electricity Distribution Network

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Disclaimer

Contact

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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 medium voltage (MV) Fuse Switch Disconnectors (FSDs) in AusNet Services' Victorian electricity distribution network.

This strategy is focused on the 150,538 single-phase FSDs protecting distribution substations, SWER substations, SWER isolating transformers, line voltage regulators, pole top capacitors and distribution network spur circuits. The main types of MV FSDs installed are Expulsion Drop Out (EDO) unit, Boric Acid Type, Powder Filled Fuse Unit, Fault Tamer Unit and Energy Limited Fuse.

Through the 1980s and 1990s large numbers of EDO type FSDs were replaced in order to minimise the bushfire ignition risk in rural areas. Hence, the existing populations of Boric Acid and Fault Tamer FSDs are relatively young. Since 2017, the Victorian Government has mandated the rollout of Rapid Earth Fault Current Limiter (REFCL) installations across nominated zone substations in AusNet Services' network. Single-phase switching operations or protection operations that do not clear faults three-phase have a risk of causing a mal-operation of the REFCL and a feeder trip as a result. This becomes more of a risk as the shunt capacitance being switched becomes larger. Moreover, back-fed faults pose a safety risk as these high impedance faults are sometimes not identified by protection. Various operations are available for addressing the risk and each fuse requires a protection review to determine the best option

In general, the failure modes of MV FSDs include; "hang-ups", "candling", bird or animal initiated arcing faults and corrosion initiated insulator failures. MV FSD failures can cause sustained supply outages, quality of supply events, bushfire ignitions and present safety risks. Since 2006, the 12-year failure rate of EDO FSDs is estimated as 0.35% per annum, followed by the Powder Filled FSDs failure rate of 0.32% per annum and Boric Acid FSDs failure rate of 0.03% per annum. A customer might experience loss of supply due to unplanned interruptions caused by MV FSD failures in an average of 0.68 minutes per event per year.

Condition assessment shows that about 37% of MV FSDs are in "Very Good" (C1) condition. EDO fuse units are in "Poor" (C4) and "Very Poor" (C5) condition, which contribute to approximately 31% of the total MV FSDs' population.

Risk analysis of MV FSDs, using quantified consequence/criticality bands, shows that EDO fuse units, which are in criticality 4 and 5 category, may be flagged for replacement due to the potential ignition risk. In order to manage the risk "as far as practicable" as per the Electricity Safety Act, it is recommended to proactively replace MV FSDs located in the high consequence effect and worst condition region.

1.1 Asset Strategies

1.1.1 New Assets

- Install Boric Acid and Fault Tamer FSDs on new MV installations
- Establish group fused SWER and single phase circuits to optimise the application of FSDs
- Install Fuse Saver units in series with selected line fuses

1.1.2 Inspection

- Inspect MV FSDs in accordance with Asset Inspection Manual *30-4111*

- Continue to monitor failure rates of discrete types of MV FSD and adjust focussed replacement programs if required
- Monitor ‘hang-up’ or ‘candling’ rate of Boric Acid Fuses
- Monitor the performance of Energy Limiting Fuse (ELF) FSDs on existing fleet

1.1.3 Replacement

- Progressively replace EDO fuse in high consequence risk areas.
- Review and replace MV FSDs as per REFCL requirement - *30-4161-09-02 HV Line Fusing Protection Design Principles*.
- In conjunction with pole or crossarm replacement, replace EDO fuses with Boric Acid or Fault Tamer units as per the Standard Maintenance Guidelines *SOP 70-03.*

1.1.4 Research and Development

- Investigate the use of mechanical fusing device (vacuum breaker) or alternative designs to replace MV FSDs.
- Establish formal procedure and standard data guideline to ensure that the quantity and type of MV FSDs are accurately recorded in the Enterprise Asset Management System SAP.

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 medium voltage (MV) Fuse Switch Disconnectors (FSDs) 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 MV FSDs protecting:

- Distribution substations
- Sections of single wire earth return (SWER) lines, and
- Single-phase spurs on medium voltage feeders in AusNet Services electricity distribution network.

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

Medium voltage (MV) Fuse Switch Disconnectors (FSDs) provide the following functions:

- Over-current protection to detect and disconnect faulty electrical equipment or sections of medium voltage line or insulated cable
- Manual disconnection facilities to isolate electrical equipment and sections of line or cable from voltage sources, which enable the application of protective earth device. Hence, it provides a safe working condition for line workers
- In conjunction with “load buster” devices, it provides single-phase switching facilities which enable the manual energisation and de-energisation of electrical equipment or sections of line or cable

	
[C.I.C] EDO FSD	Powder filled FSD
	
[C.I.C] Boric acid FSD	[C.I.C] Fault tamer FSD

Figure 1 - Four main MV FSDs

3.2 Asset Population

AusNet Services' medium-voltage electricity distribution network in Victoria has approximately 150,536 single-phase FSDs protecting distribution substations, SWER substations, SWER isolating transformers, line voltage regulators, pole top capacitors and distribution network spur circuits.

The following types of FSDs are installed on the network

- Boric Acid Type
- Expulsion Drop Out (EDO) Unit
- Powder Filled Fuse Unit
- Fault Tamer Fuse Unit
- Energy Limited Fuse

Figure 2 shows that the population of MV FSDs by type.

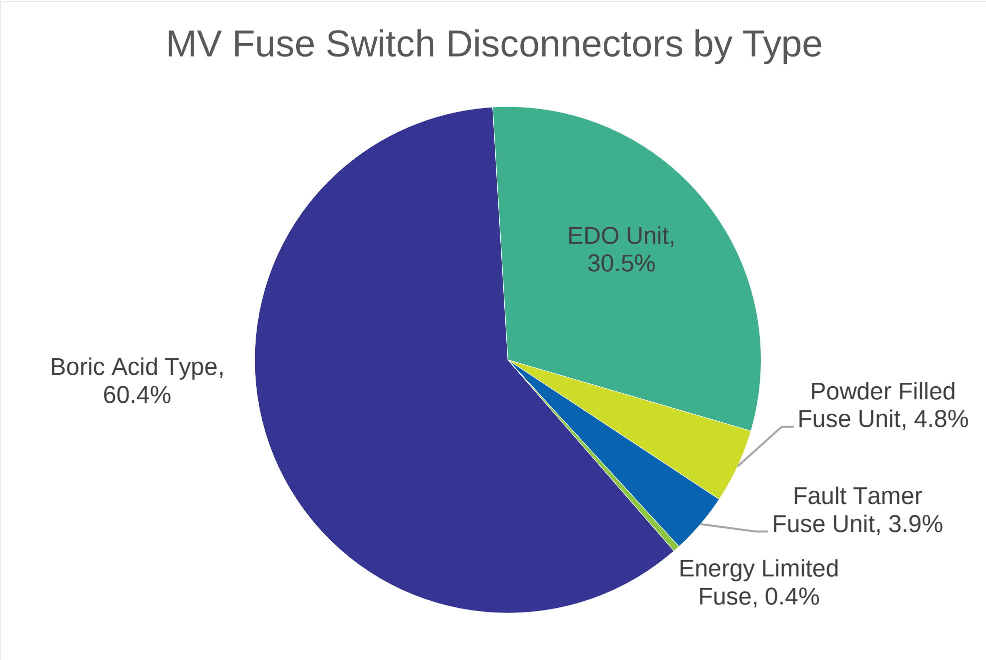

Figure 2 - MV Fuse Switch Disconnectors by Type

3.2.1 Expulsion Drop Out (EDO) Unit

Expulsion Drop Out (EDO) FSDs were introduced to the distribution network during the earliest days of electrification of the State. Earlier models of EDOs were of a type referred to as "double vented" (Figure 3), meaning when the fuse operates the hot material expulsed from both top and bottom ends of the fuse carrier. The "double vented" contact and carrier combinations presents higher risks of sustained supply outages and fire ignition due to uncontrolled expulsion of arcing products during operation and the relative ease with which birds or animals can short circuit the upper electrical contact to FSD mounting bracket.

Later models have modified fuse carriers which vent from the bottom end only into a fire choke that catches any molten fuse particles. The single-vented EDOs (Figure 4) were introduced around 1985.

In operation, the combination of a spring tensioned fuse link and the super-heated gasses created by the arc across the melted fuse link, expel the remnants of the fuse link from the fuse carrier allowing the hinges and trunnions at the base of the carrier to pivot. The pivoting motion releases the top contact of the fuse carrier from its mating contact on the fuse mount and the faulted circuit is thus disconnected.

AusNet Services ceased installing new EDO fuse units around the year 2000. The population is reducing as units are progressively removed or replaced from service

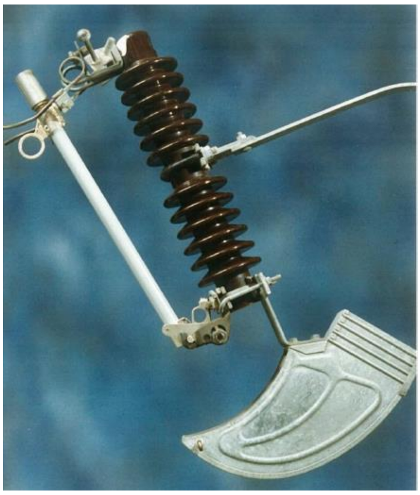

Figure 3 - EDO with double vented carrier and fixed fire choke

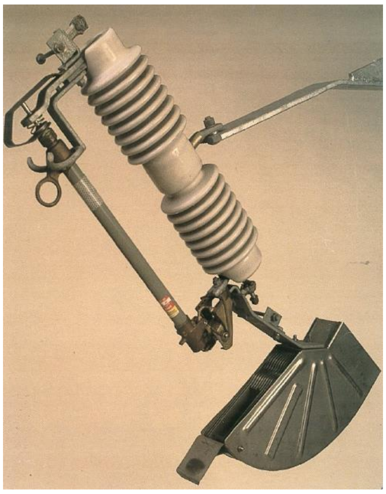

Figure 4 - EDO with single vented carrier and fixed fire choke

3.2.2 Powder Filled Fuse Unit

Powder Filled Fuse units (Figure 5 and Figure 6) are employed in high energy fault locations to protect distribution substations, line voltage regulators, underground cables and line sections. The installation of outdoor Powder Filled Fuse units ceased around the year 2000. Hence, Powder Filled Fuse units are progressively declining in number. Application of new indoor installations utilising ring main switchgear may utilise full range powder filled fuses, provided the transformer fuse size requirements are met.

Powder Filled fuse element consists of a porcelain barrel containing a fuse link wound around an insulating former. The ends of the barrel are sealed by the electrical contacts and the space between the fuse link former and the barrel is filled with quartzite sand.

When the fuse link melts the quartzite sand vitrifies, absorbing the electrical arcing energy and forming an insulating fulgurite compound. The melting of the fuse link also releases a thermal striker which drives a rod against the inside of one electrical contact to provide external indication of the correct fuse operation. Powder Filled FSDs do not trip the fuse element clear of the mounting bracket upon operation, release of the fuse element is a manual operation.

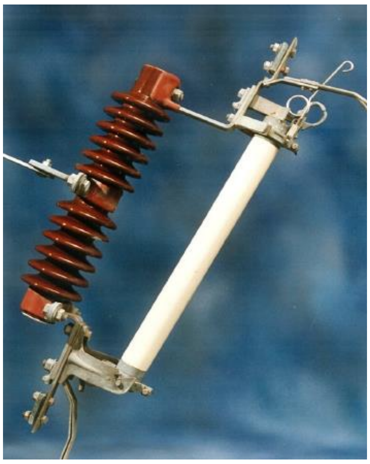

Figure 5 - Brown insulator Powder Filled FSD

Figure 6 - Grey Insulator Powder Filled FSD

3.2.3 Boric Acid Type

Boric Acid FSDs were introduced in the mid-1980s. They are currently the primary fuse protection device employed to protect distribution substations and line section. They make up approximately 60% of the total MV FSD population.

During operation, the melting of the fuse link allows a tensioned spring to draw an arcing rod through a tube lined with boric acid. The elongating arc generates high temperatures which decompose the boric acid creating water vapour and steam which extinguish the arc. The spring drives the arcing rod though a seal in the top of the fuse element to trip the latching mechanism in the top contact and allow the fuse element to pivot and disconnect the faulted circuit.

3.2.4 Fault Tamer Fuse Unit

The [C.I.C], was introduced in 2003 as a replacement for EDO FSDs. The Fault Tamer FSD has two fuse elements arranged in a series electrical circuit. The first element is designed to operate for low energy faults in a fashion similar to that of an EDO. The second element is a current limiting design to interrupt high-energy faults and operates in a manner similar to that of a powder filled fuse. It serves in the electricity distribution network to protect distribution substations and line sections in both high and low energy fault locations.

3.2.5 Energy Limited Fuse

Energy Limited Fuses (ELF) were introduced in 2013. The ELF current limiting dropout fuse is a full range current limiting fuse designed for mounting in an industry standard interchangeable fuse mount, that is presently used for EDOs and Fault Tamer Fuse Unit.

The full range current-limiting rating ensures reliable operation over a wide range of overloads and fault currents. The element construction consists of two separate actions (low-current section and high-current section) which are self-contained in a single housing. The low-current section provides consistent, reliable clearing of all currents high enough to melt the element. The high-current section is a punched-hole ribbon design which controls peak arc voltage levels and limits both current and energy (I^2t) let-through levels during high-current fault clearing operation.

The ELF dropout fuse operates relatively quietly, without expelling any material (unlike expulsion fuses). This increases safety for operational staff and reduces fire ignition risks. In addition, the drop open design makes locating the fault easy. If the ELF fuse has operated and the drop out actuator is found to be operated, then the fuse cannot be re-used. In this instance, replacement with a new ELF fuse is required.

Figure 7 - Energy Limited Fuse

3.3 Asset Age Profile

Figure 8 shows MV FSDs by service age and type.

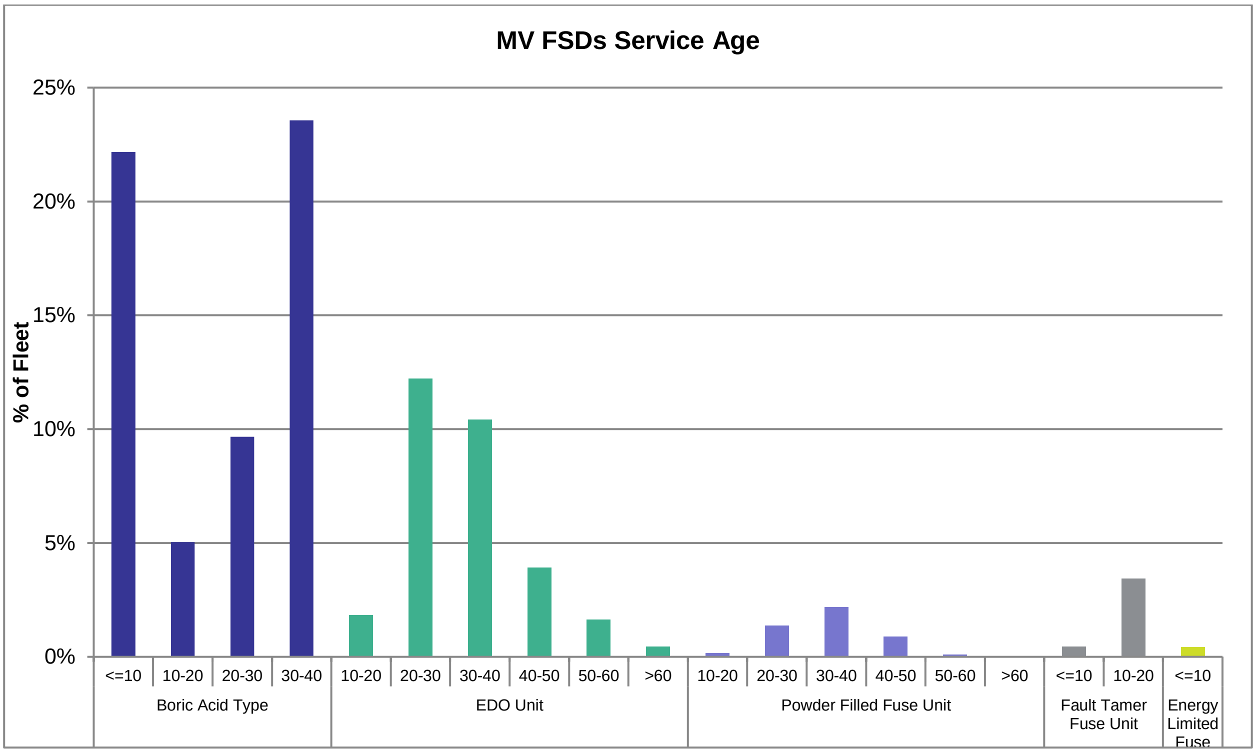

Figure 8 - MV FSDs Service Age

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 MV FSD, ranging from “Very Good” (C1) to “Very Poor” (C5). Table 1 describes the attributes, which determine the condition score rating.

Table 1 - Condition Scoring Methodology

Condition Scoring Methodology			
Condition Score	**Condition Description**	**Summary of Condition Score**	**Remaining Life**
C1	Very Good	• New condition. No known issues identified	95%
C2	Good	• Relatively new. No known issues identified	75%
C3	Average	• Some minor defects identified	60%
C4	Poor	• Considerable issues identified such as hang ups and/or fuse holder failures	45%
C5	Very Poor	• Advanced deterioration and failure such as EDO units exhibiting high hang up rates and evidence of corrosion	25%

For further detailed information regarding the condition assessment framework, specific issues, conditional maintenance activities and discussion of fails, refer to *AHR 20-61 – MV Switch Fuse Disconnector.*

3.4.1 MV FSDs Condition Summary

Condition summary for in-service MV FSDs is shown in Figure 9.

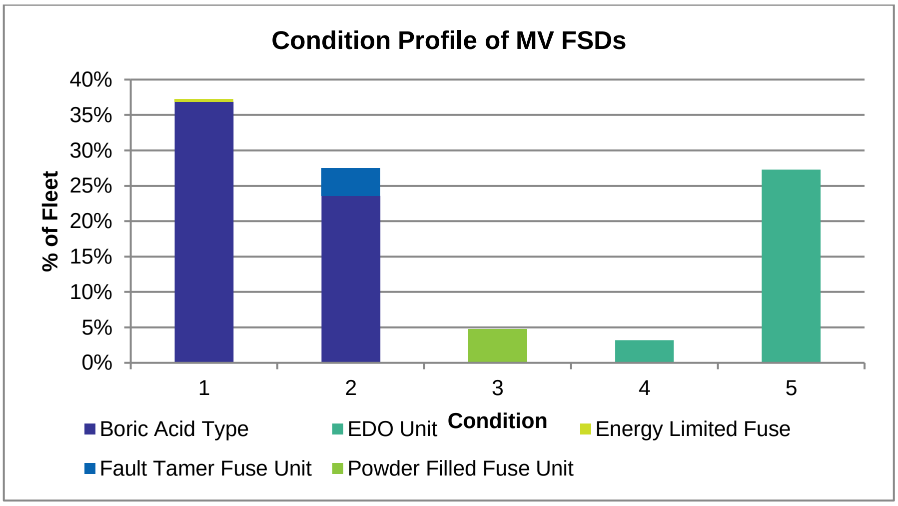

Figure 9 - Condition Profile of MV FSDs

EDO fuse units are in condition 4 and 5, which contribute to about 31% of the total MV FSDs’ population.

3.5 Asset Criticality

The consequences of MV FSDs failure are allocated into five criticality bands based on their economic impact as the result of the failure. These asset criticality or consequence impacts are irrespective of the likelihood of the actual failure

The economic impact consists of the below three components:

1. Bushfire start impact
2. Health and safety impact
3. Value of unserved energy per isolatable section when a MV FSD is malfunction

The five criticality bands are tabulated given in Table 2:

Table 2 - Criticality Band for MV FSDs

Criticality Band	Definition
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, EDO units that are in the criticality 4 and 5 category, which will be flagged for replacement due to its potential bushfire ignition risk.

Details for each impact are discussed below.

3.5.1 Unserved Energy

Failure of distribution line assets can result in system outages and unserved energy effect.

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)[1]

If a fuse "hang-ups", the value of unserved energy per isolated sections is calculated.

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

3.5.2 Bushfire Starts

The risk resulting from a bushfire start is calculated from the product of 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 2010, there have been an average of 65 MV FSD failures per annum that have led to fire ignitions. 8% of these failures cau sed ground fires.

3.5.3 Health and Safety Risk

Health and Safety risk related to the possibility that a safety consequence may occur as a result of a MV FSD failure.

Figure 10 shows the criticality for all MV FSDs.

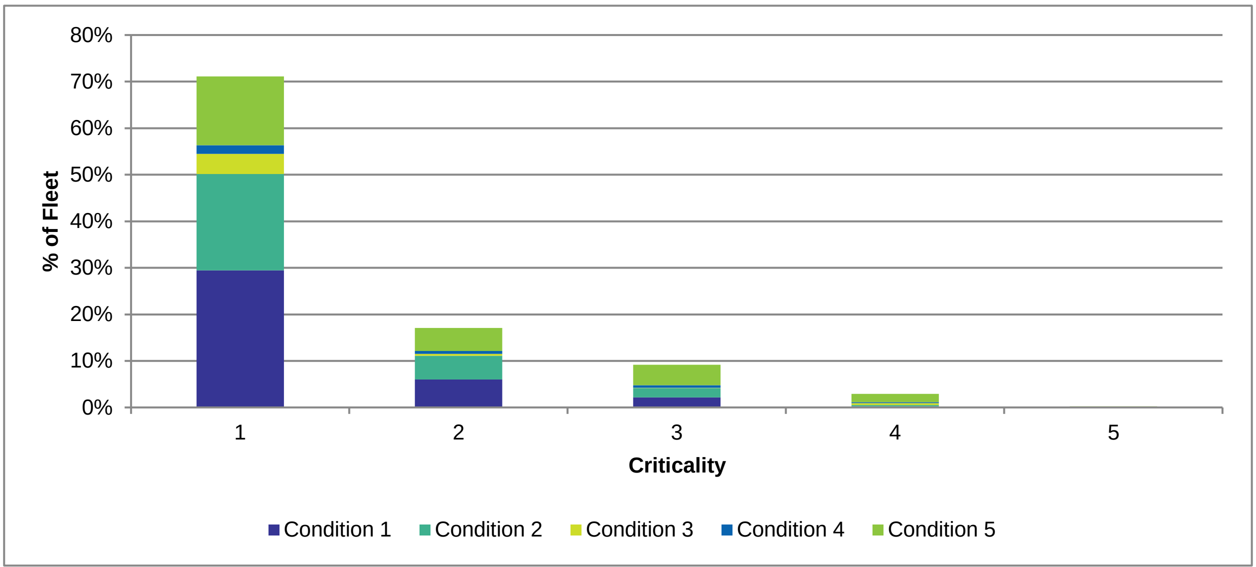

Figure 10 - Criticality for MV FSDs

3.6 Asset Performance

3.6.1 Asset Failure

The root causes of MV FSD related power failures are recorded in the Distribution Outage Management System (DOMS).

3.6.1.1. Failure by Year

Figure 11 shows the count of MV FSD related power failures per year since 2006. It is observed that MV FSDs' failures have decreased progressively since the commencement of the EDO replacement program in 2008

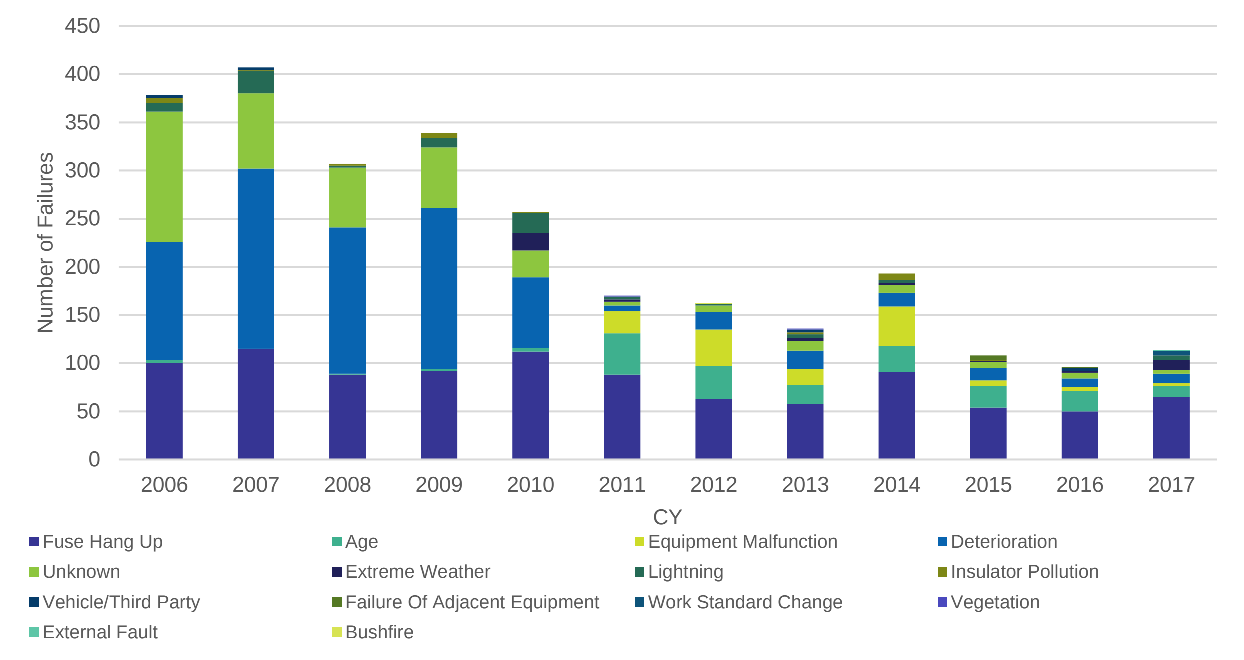

Figure 11 - Failure by Year

3.6.1.2. Failure by Cause

The majority of power failures caused by MV FSDs are due to Fuse Hang up (36%) as shown in Figure 12.

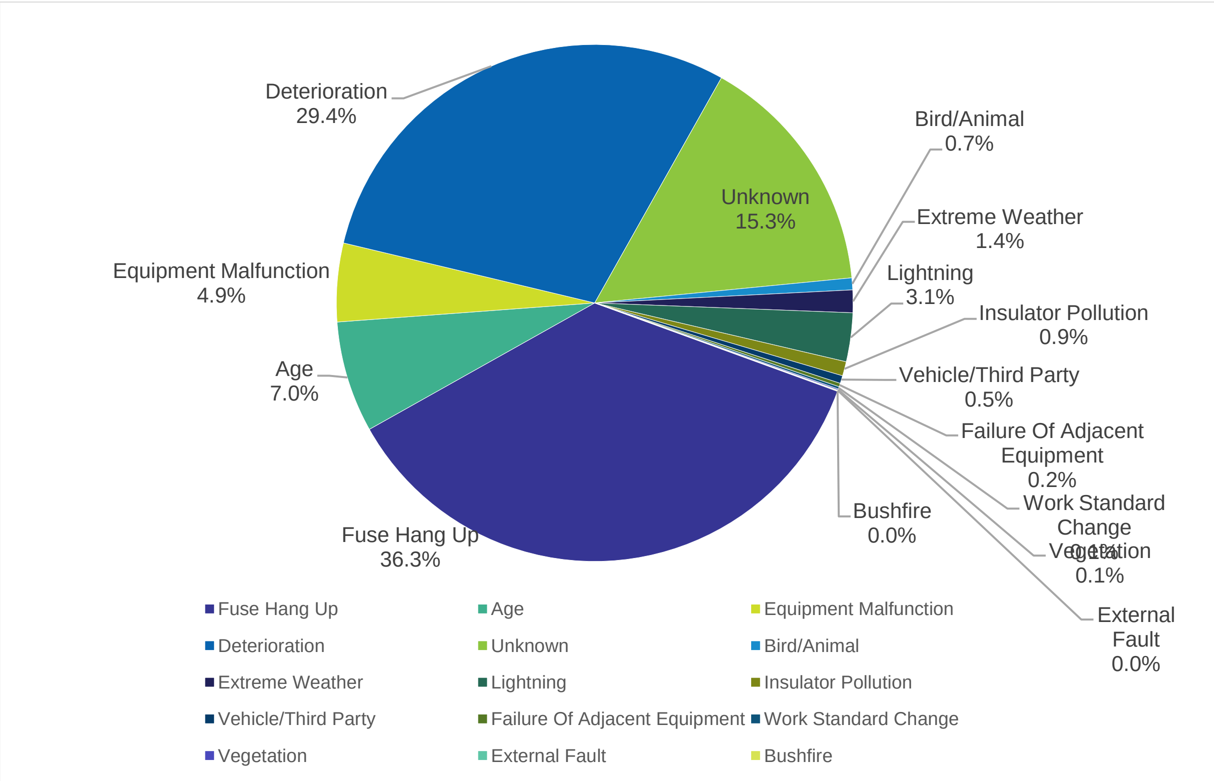

Figure 12 - Root Cause of MV FSD Related Power Failures

3.6.1.3. Failure by Fuse Type

The failure rate of EDO FSDs is estimated as 0.35% per annum, followed by the Powder Filled FSDs failure rate of 0.32% per annum and Boric Acid FSDs failure rate of 0.03% per annum, based on the 12 years' average.

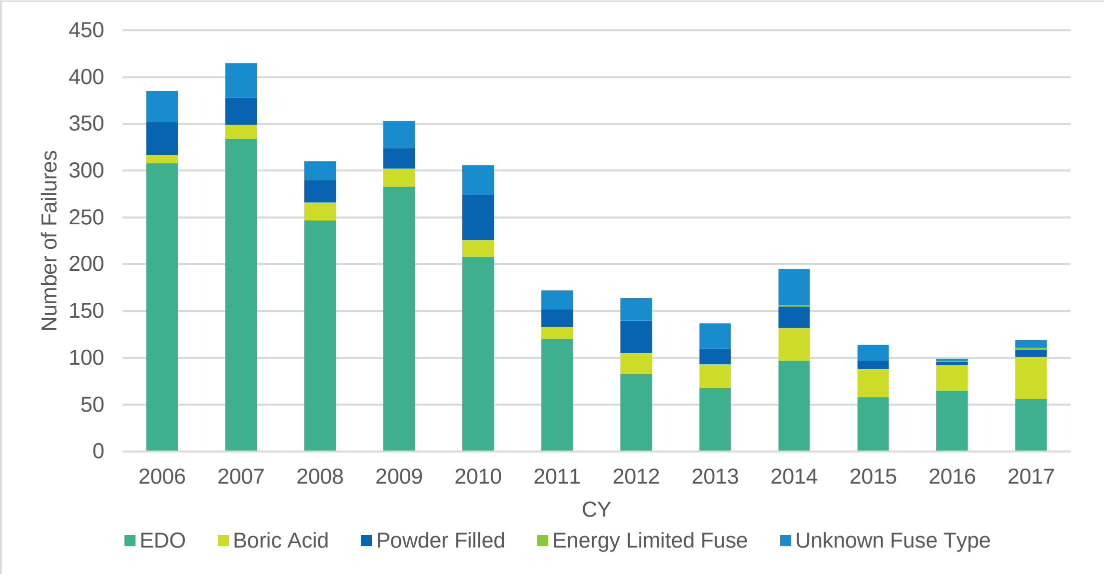

Figure 13 - Failure by Fuse Type

3.6.2 Sustain Outages

There are about 159 FSD related sustain outages reported each year. Since 2008, a customer might experience loss of supply due to unplanned interruptions caused by MV FSD failures in an average of 0.68 minutes per event per year. This has resulted in an average of Service Targe Performance Scheme (STPIS) penalty of $486k per year.

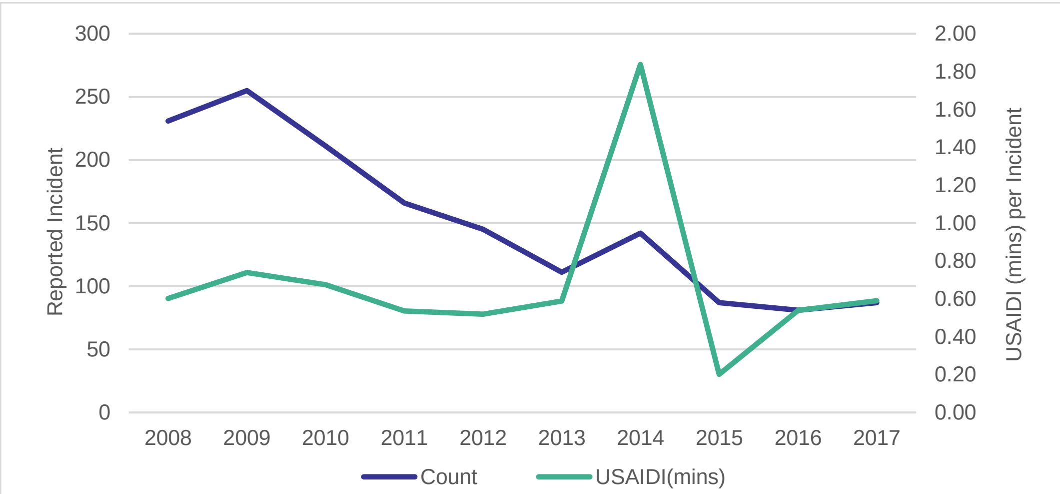

Figure 14 - Network Performance

3.6.3 Fire Ignition

Since 2006, there have been 877 MV FSD failures that have caused fire ignitions. 8% of these failure caused ground fires. Figure 15 shows the historical trend of fires related to MV FSD. The number of MV FSD related fires dropped significantly after 2010 as a result of selected MV FSD replacement program focused on high bushfire risk areas.

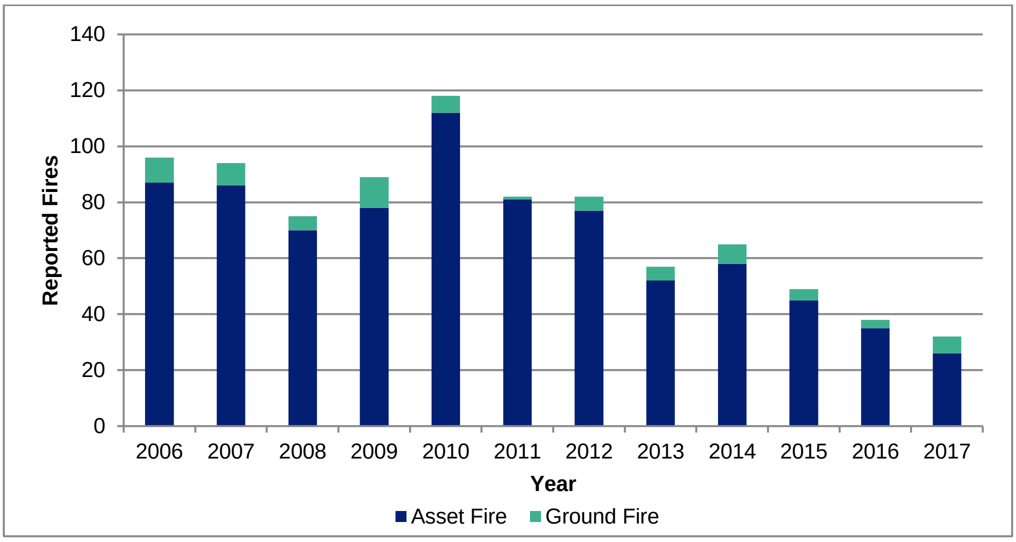

Figure 15 - MV FSD related fires

All remaining EDO units on the network have fire chokes installed. Nevertheless, EDOs can still cause ground fires due to ‘candling’ or ‘hang-up’, where the mode of failure is the fuse tubes catching fire and hot pieces falling to the ground.

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. REFCL performance criteria specified in *REF 30-09 Maintaining Capacitive Balance Policy* requires the dissymmetry of the network to be less than 100mA. As with the *REF 30-06 Network Capacitive Balancing Policy*, AusNet Services will maintain the balance of each three-phase automatic circuit recloser (ACR) and each sectionaliser section so that a switching operations should not cause the neutral current to be displaced by more than 100mA.

Single-phase switching operations or protection operations that do not clear faults three-phase have a risk of causing a mal-operation of the REFCL and a feeder trip as a result. This becomes more of a risk as the shunt capacitance being switched becomes larger. Moreover, back-fed faults pose a safety risk as these high impedance faults are sometimes not identified by protection.

Various operations are available for addressing the risk and each fuse requires a protection review to determine the best option, which include:

- Replacing a number of fuses with an ACR
- Re-conducting
- Installing a new version of the Fusesaver
- Replacing the fuse units with a solid link
- Reliability review of the likelihood a fuse operation

Details of these options can be found in *30-4161-09-02 HV Line Fusing Protection Design Principles*.

4.2 Inspection

MV FSDs are being inspected as part of the routine line inspection as per the *Asset Inspection Manual 30-4111* and supported by the *HV Fuse and Surge Arrester Identification Manual 30-4162*.

The inspection includes visual assessment of MV FSDs and recording of any defects. If fuse units show signs of deterioration indicating that the units may fail prior to the next scheduled inspection, a notification for rectification will be raised in the Enterprise Asset Management System – SAP.

The standard maintenance guideline of MV FSD is detailed in the *SOP 70-03*.

4.3 Installation & Replacement

EDO fuse units are no longer being installed on new and replacement work. They are being replaced with Boric Acid or Fault Tamer fuse units. Historical EDO targeted replacement volume can be found in the Electricity Network Works Program document[2].

[2] Electricity Networks Works Program FY19-FY23

As part of the pole or crossarm replacement, EDO and Powder Filled Fuse units will be replaced at the same time. Fuse units will be replaced by either Boric Acid or Fault Tamer units.

MV FSDs located in the REFCL areas are currently under review at the time of the writing and may subject to replacement as outlined in Section 4.1.

4.4 Future Developments

AusNet services is currently investigating the use of a mechanical fusing device (vacuum breaker) to replace MV FSDs, which will offer following advantages.

- Eliminate fuse hang-ups resulting in no fire risks;
- Can be easily insulated to offer animal/bird protection; and
- Tripping can be synchronised to achieve three-phase switching specially in REFCL areas.

It is intended that these new devices to be initially used on new installation in REFCL areas and specified codified (high bushfire risk) areas.

4.5 Failure Modes

Failure modes for each MV FSD type are described below.

4.5.1.1.1. EDO

The [C.I.C] fuse link used in EDO type FSDs has proven susceptible to hang-ups (also known as candling) during low energy faults. To a lesser degree, the [C.I.C] has also proven susceptible to hang-ups arising from lightning initiated or low energy faults. The [C.I.C] fuse link has a history of strain cord failures resulting in unnecessary supply outages.

Early model EDO fuse carriers are prone to weathering, electrical tracking, corrosion of hinge pivots and arcing damage to top contacts. Post 1989 fuse carriers have higher mechanical strength, superior weathering resistance and greater electrical insulation but are still prone to arcing damage on the top contacts. Deterioration is accelerated in aggressive coastal environments and high rainfall areas such as Alpine forests.

EDO insulators have proven susceptibility to electrical tracking in high pollution areas such as those near the Gippsland coast. The cement securing the galvanised steel mounting bracket in the porcelain insulator has also failed in a marine environment. Essentially, mounting insulators have a relatively long life but corrosion, arcing damage and loss of spring tension in the electrical contacts determine end of practical life. It is not economic to refit contacts to existing mounting insulators.

4.5.1.1.2. Boric Acid

Moisture ingress over a long period may cause the internal metal parts to corrode and seize the operating mechanism thereby resulting in hang-ups.

AusNet Services experienced a number of Boric Acid ‘fuse hang-ups’ across the network. Extensive investigations involving manufacturers were carried out to find the root cause and rectify the problems. No conclusive evidence to pin point a particular cause was able to be determined.

AusNet Services has since approved a new supplier to source a sealed fuse tube. However, it is too early to come to any conclusion on the performance of these sealed type against the breathing types.

4.5.1.1.3. Powder Filled

The fuse barrels used in powder filled FSDs are relatively fragile as they are made of porcelain and require careful handling, transport and storage. Mechanical damage presents the operator with safety hazards associated with sharp porcelain fragments.

Three-inch diameter powder filled fuse elements are too heavy to handle by operating sticks. Operators must hand fit these fuse elements from an elevating work platform.

Some fuse elements for powder filled FSDs are not rated for correct operation across the broad range of fault currents experienced in the distribution network. Misapplication of such limited range units usually means correct operation for high energy faults but presents the possibility of “candling” (smouldering) and failing to adequately clear low energy fault currents.

“Candling” occurs when the fuse element continues to conduct low level of fault current and generates significant heat in the contents and insulting barrel of the fuse element. Under such conditions the fuse element becomes fragile and can disintegrate when disturbed by an operator and falling porcelain fragments, molten silica and hot metal fittings present a serious safety risk.

External arcing faults from the powder filled mounting bracket to the top or bottom electrical contacts is predominantly initiated by birds or animals bridging the air space between the energised portions of the FSD and the earthed portions of a pole or crossarm.

4.5.1.1.4. Fault Tamer

Fault Tamer fuses were introduced around 2003 and were mainly used on substation structures. During the initial days, there were few fire related incidents. However, with some improvements to the product, performance of these fuse units has been satisfactory. They are not considered as a major bushfire risk item.

4.5.1.1.5. Energy Limited Fuses

At the time of writing, Energy Limited Fuse operation has been satisfactory and no major failures have been reported.

5 Risk and Options Analysis

This section outlines the key risks presented by MV FSD and to discuss how these risks should be addressed.

5.1 Risks

The risk matrix, showing condition and consequence, of MV FSDs located in a non-REFCL area is tabulated in Table 3

Table 3 - Risk and Condition Matrix of MV FSD in non-REFCL region

		Condition – MV FSDs in non-REFCL area					
		1	2	3	4	5	Quantity
Criticality Band	5	12	17	0	5	350	383
	4	343	356	7	290	2555	3551
	3	3174	2825	113	787	6408	13307
	2	8705	7391	653	848	7221	24817
	1	42831	30105	6368	2682	21441	103427
	Quantity	55065	40694	7141	4612	37974	145486

In Table 3, the greatest risks appear in the top right corner, whereas the lowest risks are in the bottom left corner.

5.2 Options

5.2.1 Proactive Replacement

As discussed in Section3.6.3, even with a fire choke installed, EDOs can still cause ground fires due to “candling” and “hang-ups”. Thus, all EDOs are considered as a high risk and a targeted replacement program has been introduced to mitigate the risk

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

MV FSDs may also be replaced with other asset replacement works. SAP notification analysis shows that an estimated one-third of MV FSDs will be replaced due to this reason.

Protection review on MV FSDs located in the REFCL area is currently underway at the time of writing. Details of the review are outlined in Section 4.1. Moreover, SAP data cleansing for MV FSDs located in the REFCL region is in progress to ensure that the quantity and type of MV FSDs are accurate in the data system.

In order to manage the risk "as far as practicable" as per the Electricity Safety Act, it is recommended to proactively replace MV FSDs located in the high consequence effect and worst condition region as shown in red in Table 3.

5.2.2 Reactive Replacement

Historical fault analysis shows an estimated count of 325 fuse units will be reactively replaced per annum in non-REFCL areas. The volume of future reactive replacement is expected to be similar.

5.2.3 Overall Replacement Forecast

As the result of the risk and options evaluation, the replacement forecast is summarised in Table 4.

Table 4 - Replacement Forecast

Identifier	Justification	Contribution per Annum
Proactive Replacement	Probabilistic replacement on asset with high consequence effect and worst condition	1326
Reactive Replacement	Probabilistic replacement due to defect or fault	325
	Total Replacement	1651

In summary, an estimated count of 1651 fuse units will be replaced per annum in 2022 – 2026.

6 Asset Strategies

6.1 New Assets

- Install Boric Acid and Fault Tamer FSDs on new MV installations
- Establish group fused SWER and single phase circuits to optimise the application of FSDs
- Install Fuse Saver units in series with selected line fuses

6.2 Inspection

- Inspect MV FSDs in accordance with Asset Inspection Manual *30-4111*
- Continue to monitor failure rates of discrete types of MV FSD and adjust focussed replacement programs if required
- Monitor 'hang-up' or 'candling' rate of Boric Acid Fuses
- Monitor the performance of Energy Limiting Fuse (ELF) FSDs on existing fleet

6.3 Replacement

- Progressively replace EDO fuse in high consequence risk areas.
- Review and replace MV FSDs as per REFCL requirement - *30-4161-09-02 HV Line Fusing Protection Design Principles*.
- In conjunction with pole or crossarm replacement, replace EDO fuses with Boric Acid or Fault Tamer units as per the Standard Maintenance Guidelines *SOP 70-03.*

6.4 Research and Development

- Investigate the use of mechanical fusing device (vacuum breaker) or alternative designs to replace MV FSDs.
- Establish formal procedure and standard data guideline to ensure that the quantity and type of MV FSDs are accurately recorded in the Enterprise Asset Management System SAP.