AMS – Victorian Electricity Transmission Network

Surge Arresters (PUBLIC VERSION)

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1 Executive Summary

This document defines the asset management strategies for a population of 2,139 surge arresters in AusNet Services' Victorian electricity transmission network.

Surge arresters protect expensive plant from over voltages caused by lightning strikes or transient switching voltages.

The population of surge arresters is predominantly gapless metal oxide (approximately 97%) and the remainder are gapped silicon carbide (approximately 3%), and based on housing the population of surge arresters are 27 per cent of porcelain housed units and 73% of polymer housed units respectively.

The primary focus is on the replacement of the of silicon carbide surge arresters that have porcelain housings (currently in poor condition) with the metal oxide type with polymer housing.

In comparison to the more modern polymer housed units, failures of ageing surge arresters with porcelain housings pose a significantly higher safety risk that has an accompanying risk of collateral damage.

Currently, 3 per cent of the surge arrester population are in "poor" and "very poor" conditions and should be replaced over the next 10 years.

1.1 Strategy Summary

The following summarises the key surge arrester asset management strategies:

- Complete replacement of 90% of the silicon carbide surge arresters (this constitutes 100% of surge arresters carrying risk of high impact failure will be replaced) by 2020.
- Complete replacement of surge arresters in conditions C4 (poor) and C5 (very poor) by the end of 2022.
- Where possible, coordinate the replacement of silicon carbide, C4 and C5 surge arresters with major station or plant replacement works.
- Commence investigation on the first generation porcelain housed metal oxide surge arresters for condition deterioration.
- Investigate the economic viability of implementing an online condition assessment program to benchmark the condition of metal oxide surge arresters.

2 Introduction

2.1 Purpose

The purpose of this document is to define the asset management strategies for the population of surge arresters in the Victorian electricity transmission network.

2.2 Scope

This asset management strategy applies to 500 kV, 330 kV, 275 kV, 220 kV, 66 kV and 22 kV rated surge arresters in the Victorian electricity transmission network.

2.3 Objectives

The objectives of this asset management strategy are to:

- present an overview of the surge arrester population;
- manage business and network risks presented by surge arresters efficiently and to within acceptable limits;
- achieve supply availability targets taking account of risk, costs and customer expectations;
- ensure the effective and consistent management of surge arresters throughout their life-cycle; and
- demonstrate that surge arresters are being managed prudently throughout their life-cycle.

2.4 References

This asset management strategy forms part of a suite of documentation that supports the management of AusNet Services' assets, which include the following:

AMS 01-01	Asset Management System – Overview
AMS 10-01	Asset Management Strategy – Transmission Network
AMS 10-19	Plant and Equipment Maintenance

3 Asset Summary

Surge arresters are devices used on electrical power systems to protect critical, or high value items of plant that are susceptible to internal failure due to transient lightning or voltage surges during switching. They are typically installed adjacent to gas insulated switchgear, on the high voltage and low voltage sides of power transformers, and at the terminations of HV and EHV cables /overhead lines.

Figure 1 shows an early generation porcelain-housed silicon-carbide surge arrester and a contemporary polymer-housed metal-oxide surge arrester.

66 kV Porcelain housed Silicon Carbide surge arrester

220 kV Polymer housed Metal Oxide surge arrester

Figure 1 – Silicon carbide and modern metal oxide surge arresters

3.1 Population

There is a total of 2,139 surge arresters installed in the Victorian electricity transmission network[1]. The population of surge arresters by voltage class is shown in Table 1 and represented in Figure 2 below.

Voltage Class	Quantity
500 kV	134
330 kV	45
275 kV	6
220 kV	653
66 kV	1164
36 kV	3
22 kV	134
Total	**2139**

Table 1 – Population of surge arresters

[1] AHR 10-73 – Surge Arresters.

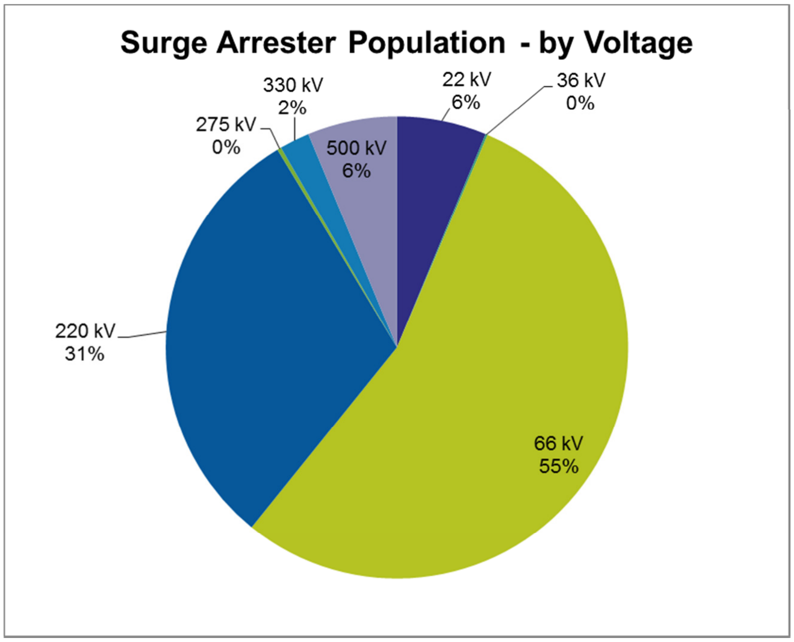

Figure 2 – Surge arrester population by voltage

Prior to the 1980s, all surge arresters were the gapped silicon carbide type. Since then, all surge arresters installed have been the gapless metal oxide type. There are currently 97 per cent of gapless metal oxide and 3 per cent of silicon carbide surge arresters in the transmission network.

Prior to 2000s surge arresters generally had porcelain housings, but since then all the metal oxide surge arresters installed have polymer housings. Therefore, all the existing silicon carbide arresters and the first generation of metal oxide surge arresters have porcelain housings.

Figure 3 indicates the percentage of surge arrester by block/housing types – Porcelain silicon carbide (SiC) and Porcelain metal oxide (MO) and Polymer metal oxide.

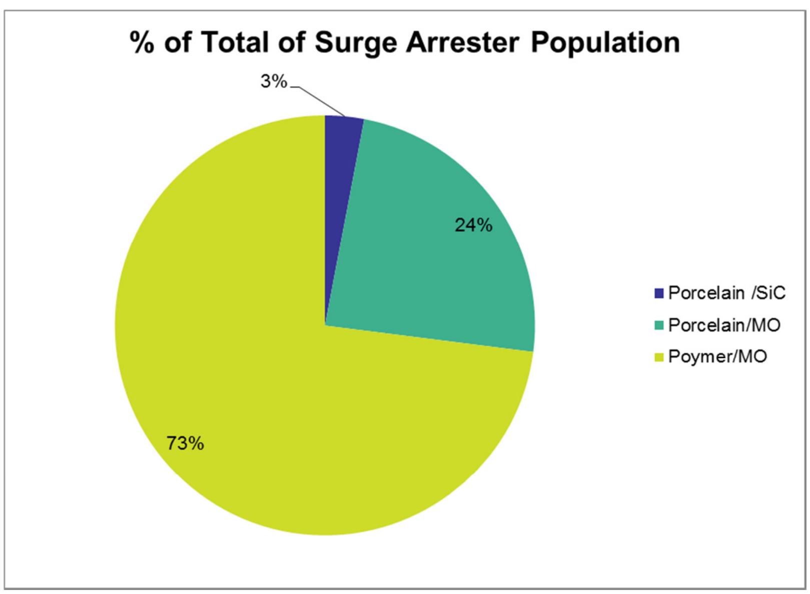

Figure 3 – Total population of surge arresters separated by block/housing type

The population of surge arresters has seen an increase due to network growth and increased use of surge arresters instead of protective air gaps in the EHV operating voltages of 220 kV, 275 kV, 220 kV and 500 kV.

The majority of EHV surge arresters are installed to protect 220 kV power transformers, which have a lower insulation impulse withstand capability compared with other EHV equipment. Increasingly surge arresters are also being installed at EHV line ends to replace the existing simple but less effective line entry protective air gaps. The majority of the 66 kV and 22 kV surge arresters are installed on feeder bays as overhead lines at those voltages have no earth wire for lighting protection.

3.2 Age Profile

The service age of the surge arresters in service vary from 0 to 66 years. The oldest metal oxide types are now approximately 36 years old.

The service age profile for surge arresters is shown in Figure 4 below.

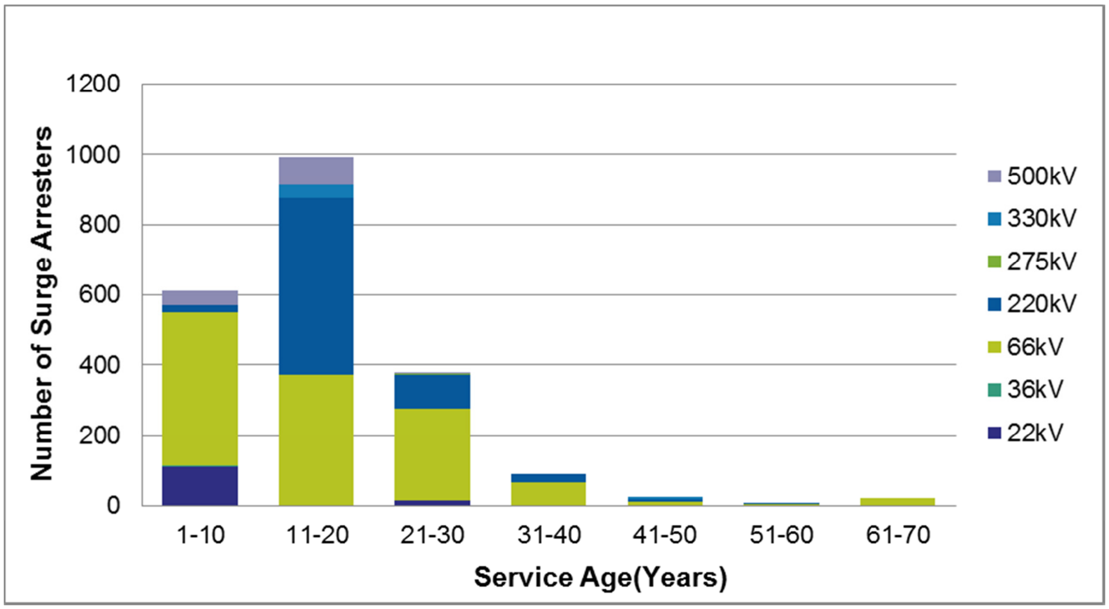

Figure 4 – Service age distribution of surge arresters

3.3 Condition

The general condition of AusNet Services' surge arresters is good as many units were replaced / installed in the last decade

Table 2 provides a definition of the various condition scores and recommendations which was used to assess the surge arrester population.

Condition Score	Condition Description	Recommended Action
C1	Very good or original condition	No additional specific actions required, continue routine maintenance and condition monitoring.
C2	Better than average for age	
C3	Average condition for age	
C4	Poor	Remedial action/replacement within 2-10 years
C5	Very poor and approaching end of life	Remedial action/replacement within 1-5 years

Table 2 – Condition score definition and recommended action

A condition score of C1 to C3 corresponds to an acceptable condition where no additional action (apart from continued routine maintenance and condition monitoring) is proposed. However, a condition score of C4 or C5 corresponds to surge arresters with high to very high risk of failure requiring remedial action within a relatively short time frame.

Figure 5 shows the condition of the surge arresters in the transmission network.

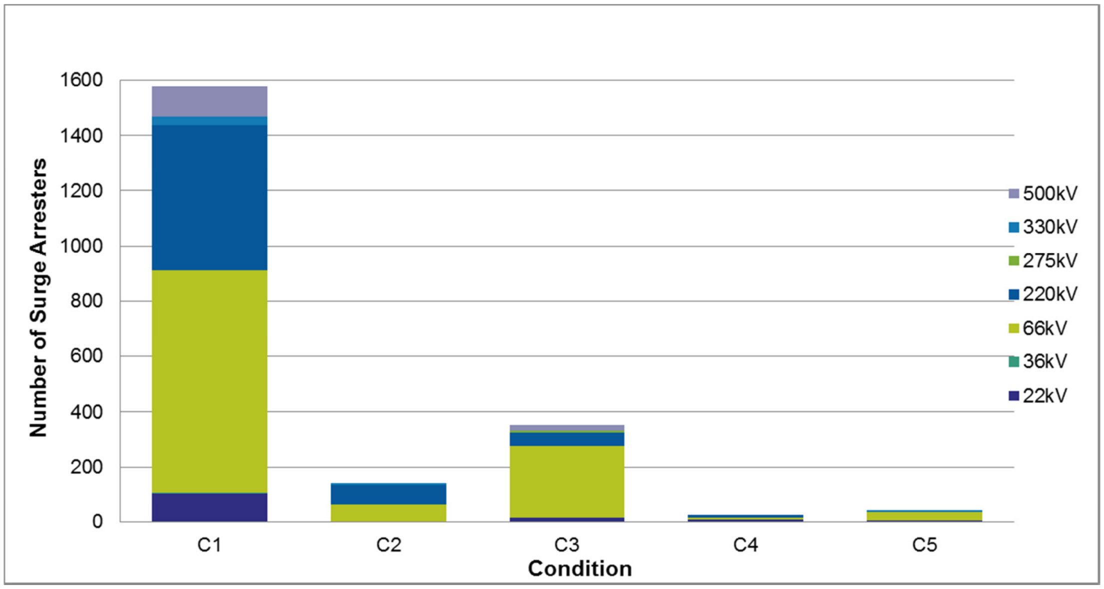

Figure 5 – Condition of Surge Arresters

The condition of 81 per cent of surge arresters fall under the C1 & C2 category.

The condition of 3 per cent (66) of surge arresters fall under C4 and C5 categories, which need to be addressed within the next 10 years. All these 66 surge arresters are gapped silicon carbide with porcelain housing.

3.4 Performance

This section provides an overview of performance issues associated with surge arrester population and provides Failure Modes, Effects and Criticality Analysis (FMECA).

3.4.1 Defects and Failures

Surge arresters generally reach the end of their life when:

- Performance deterioration of voltage / impedance characteristics, beyond acceptable limits.
- Corrosion or deterioration of seals allows moisture to enter the arrester housing.
- Surge Arrester is subjected to energy dissipation levels beyond design limits.

Performance Deterioration

Silicon carbide surge arrester performance deteriorates with the number and magnitude of arresting operations. Therefore, in high incidence areas, silicon carbide surge arresters are often replaced when they reach a pre-determined number of arresting operations.

Manufacturers claim that metal oxide surge arrester performance does not deteriorate with the number of arresting operations. To date, we have not experienced any evidence to the contrary across the transmission network. Deterioration of the metal oxide blocks has however occurred with two specific surge arrester models, but these are understood to have been type/batch defects.

Corrosion / Physical Deterioration

In many cases the corrosion or deterioration of housing seals will determine the technical life of surge arresters, especially when the operating duty is very low and performance deterioration is not significant. The presence of moisture, humidity or other contamination within the surge arrester housing affect the operation of internal spark gaps and hence impact on its correct functioning and reliability. Internal moisture can also create overpressure and if on-board safety devices function as designed, the overpressure results in emergency automatic venting, that is a low impact, but permanent form of failure.

A small group of the oldest surge arresters were not designed with over-pressure venting devices but the reliability of the rupture plates associated with the venting devices is limited to approximately 30 years. Where this operational life has been exceeded, the performance of the rupture plates cannot be guaranteed, so the pressure relief devices must be considered ineffective. In these cases, an overpressure event caused by build-up of internal moisture can result in rupture of the porcelain housing, resulting in a high impact failure.

Surge arresters that have polymer housings do not use seals. The polymer insulation is moulded directly onto the reinforced metal oxide blocks. This construction method is intended to eliminate the risk of seal failure and moisture entry into the surge arrester housing.

Dissipation of Excessive Energy Levels

All forms of surge arresters are likely to fail in the event of extreme overload, such as continuous flow of network fault current, or exposure to lightning / network transients beyond the designed duty.

Polymer insulated metal oxide arresters, are often designed without the need for overpressure vents, but there can be an internal material breakdown that produces gaseous plasma. Pressure from these gases can then lead to elastic expansion of the polymer housing and the universal design criterion is that the housing will ultimately burst to release excessive pressure.

Known Defects

Silicon Carbide type

Known major defects identified on in-service silicon carbide surge arresters include:

- [C.I.C] (330 kV, 66 kV, 22 kV) – These surge arresters were installed in the 1960s and 1970s and are some of the oldest surge arresters still in operation on the system. They are nearing the end of their technical life. They utilise a system of silicon carbide blocks and internal spark gaps to achieve the required performance. Due to the service age of these units, atmospheric housing seals cannot be guaranteed and they must be considered prone to the ingress of moisture, humidity or other contamination. A failure resulting from such contamination may be expected to have a high consequential impact. As yet, no such failures have occurred with the current fleet of surge arresters, but due to the high consequential risk, all [C.I.C] have either already been replaced or are approved for replacement.
- [C.I.C] (22 kV& 66 kV) – these surge arresters can suffer from seal corrosion and moisture entry, leading to over-pressure venting/failure. These surge arresters were installed in the 1960s and due to the high consequential risk, all have now been replaced or scheduled for replacement.
- [C.I.C] (66 kV to 500 kV) – these surge arresters experience severe electrolytic corrosion, leading to housing seal failure. Three failures have been recorded. [C.I.C] have previously advised that failure will follow rapidly after corrosion reaches a certain stage. All have now been replaced or scheduled for replacement.

Metal Oxide type

Known major failures that have occurred:

- [C.I.C] type – a mid-1980's vintage porcelain housed surge arrester design. In 2010 there was operation and venting/internal failure of 500 kV [C.I.C] type at LYPS (owned by the power station) and two off 330 kV [C.I.C] type venting/internal failures at WOTS (on 91/1/10 and later 2/2/10). Both are a similar design and both types are approximately 25 years old. In these cases the failure mode was benign. The LYPS failure has been linked to pollution effects. The WOTS failures have been attributed to deterioration of the metal oxide block characteristics. There was an [C.I.C] surge arrester product recall in the mid 1980's and many [C.I.C] surge arresters were replaced. These [C.I.C] type were not replaced in the mid 1980's, but may have been subject to the original recall defect. This type has now been all replaced or scheduled for replacement.

- [C.I.C] – In February 2011, a 500 kV polymer housed surge arrester that had been installed at HWTS in 2000, operated/vented and failed in the absence of any system incident. Failure mode was safe. There was no evidence of moisture entry and the investigation was inconclusive, but there have been no subsequent failures of a similar nature. In the absence of a network transient that could have initiated the event, it has been assumed that the failure was an isolated material / batch defect.

3.4.2 Impact of Failure

Surge arresters are sacrificial items of equipment and are meant to operate, or fail before the more expensive items of equipment they are protecting. The forms of failure described in Section 3.4.1 can be classified into Low Impact failure (negligible risk of consequential loss), or High Impact failure (high risk of consequential loss).

Low Impact Failures

When an overpressure event occurs on surge arresters with ceramic housings (and some early polymeric housings), overpressure gas/plasma is designed to vent to the external surface of the housing. This high energy gas/plasma may contain contaminants and in combination with the fault current energy, external arcing can occur. The failure is generally confined to the surge arrester however, with no collateral damage to adjacent apparatus. Only a resultant outage of the related major item of apparatus is required for replacement of the surge arrester. Based on past experience, this would result in an outage of the order of 8 –12 hours.

The most recent surge arresters featuring direct moulded polymer housings are less likely to fail due to internal contamination and overpressure, but bursting can occur due to exposure from excessive energy levels. Bursting events are rare, but those that have occurred resulted in small break-away fragments of the polymer housing being dissipated over tens of metres. The material is soft in comparison to ceramic housings and consequential physical damage has not been identified to date.

High Impact Failures

Overpressure vent failures can occur on surge arresters that are prone to corrosion and that are operating significantly beyond their design lifespan (typically a maximum of 30 years). The initiating event is similar to the low impact overpressure scenario. In this case however, the safety vent fails to operate and pressure continues to build-up, ultimately causing the ceramic housing to fracture. Once a crack develops, the ceramic housing can fail explosively, breaking into numerous sharp fragments/shards. Such failures are a safety hazard to personnel and there is a high risk of collateral damage to adjacent apparatus, which will necessitate sustained outages to effect repairs.

The major vulnerability in this scenario would be collateral damage to bushings on transformers. Assuming that appropriate spares are available, it is expected that outage duration of the order of five days would be required to effect a bushing change.

Under a worse scenario, the surge arrester failure could involve the transformer in a fire for which repair costs in the order of [C.I.C] are likely. Additionally, under this scenario, sustained loss of a transformer, particularly during summer loading conditions, would pose serious security problems for the transmission network. For example, the estimated community cost of failure of a 220/66 kV transformer at Heatherton Terminal Station (HTS) is [C.I.C] in 2012/13 increasing to [C.I.C] in 2017/18.

The worst case scenario would result in injury to a person, most likely a worker in the switchyard.

4 Risk Assessment

This section discusses the risk assessment of the surge arrester fleet in the Victorian electricity transmission network.

Reliability Centred Maintenance (RCM) techniques were used to develop optimised asset replacement programs. A risk management framework has been developed aimed at reducing risks associated with surge arresters.

4.1 RCM Modelling

Reliability-Centred Maintenance (RCM) is the process of determining the most cost effective maintenance and asset management approach to providing a service or a product, in this case electrical energy. The RCM philosophy employs sound maintenance and asset management techniques as part of an integrated process to increase the probability that an asset will function as required over its design life cycle. RCM techniques use Weibull principles to model time based probabilities of failure for specific assets supporting the development of quantitative risk models.

Condition assessments of surge arresters are used to determine Remaining Service Potential (RSP) as shown in Figure 6.

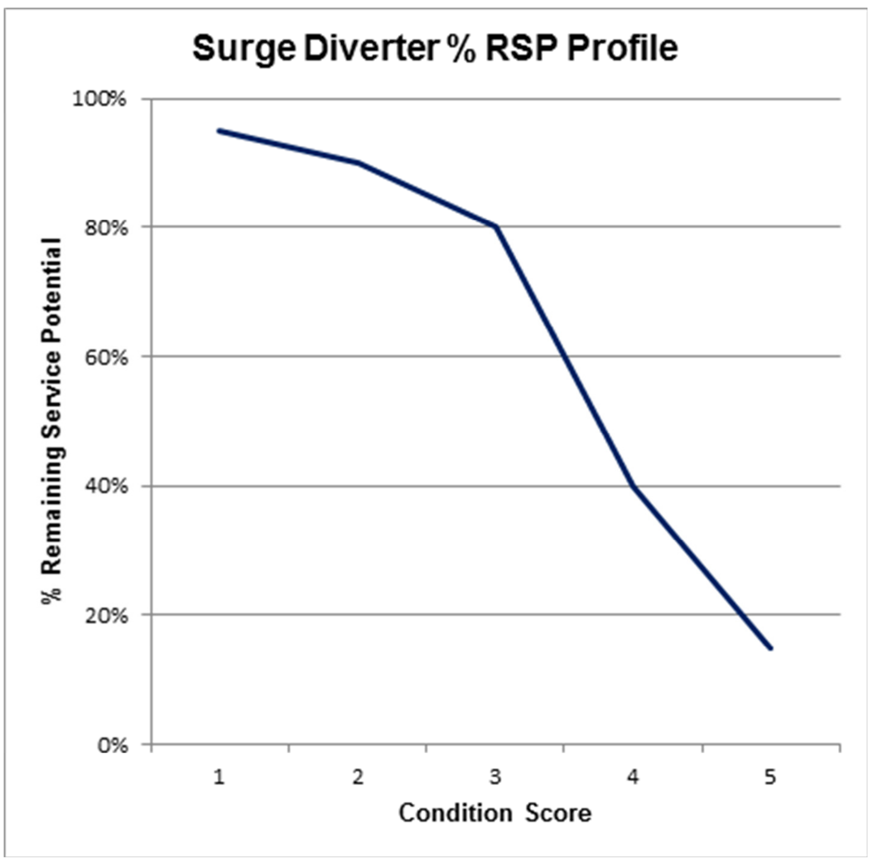

Figure 6 – Remaining Service Potential profile of surge arresters

4.1.1 Model Inputs

Functions and Functional failures – the first steps in developing RCM risk models is to assign functions and functional failures to each asset. This process enables the asset manager to determine when an assets performance level has dropped below an acceptable limit. Functions and functional failures were assigned against each surge arrester within the RCM risk model.

Failure Causes – a key aspect of RCM techniques is the determination of failure root causes for each mode of failure. Failure Mode Effect Analysis (FMEA) revealed that corrosion or deterioration of seals is the most prevalent root cause of failure which can be managed through targeted asset replacement programs.

Failure Effects – quantification of failure effect costs was performed for each surge arrester. Effect costs were objectively calculated against each of the possible failure effects discussed in section 3.4.2 including health and safety and collateral damage. The total failure effect cost for each asset was taken as the sum of all failure effects.

Failure characteristics – probability of asset failures were calculated in the RCM risk model using Weibull principles. Key Weibull parameters such as useful life (η), initial age, failure free period (γ) and shape (β) were specified. Weibull parameters specified reflect condition and performance characteristic of surge arresters for different lifecycle phases.

Replacement costs – in order to develop optimised replacement programs RCM risk models require asset replacement costs as an input. Replacement costs for each and individual surge arrester were used for RCM analysis.

4.1.2 Model Outputs

The output of AusNet Services' RCM risk models for asset risk profiles display fleet-wide annual risk costs for a specified period of time. Asset risk profiles provide asset managers with a long term view of the surge arrester fleet giving insight into how network risk may change over time. Figure 7 displays the risk profile for surge arresters if no proactive replacements take place over the period from 2012 to 2031.

[C.I.C]

Figure 7 – Surge Arrester 20 year risk profile[2]

RCM risk profiling for the surge arrester fleet demonstrates a steady increase in risk in the period 2012 – 2031. The annual risk increase is amplified by more than [C.I.C] times at the end of 20 year period if no preventative maintenance (planned replacement) is taken to mitigate the risk.

[2] Surge Diverters - PM Disabled_20yr.awbx.

4.2 Summary of the Output from Risk Model

RCM risk modelling techniques have been applied to the entire surge arrester fleet in order to determine the need for a prioritised replacement program. This approach has employed probabilistic risk modelling techniques to establish a targeted and economic replacement program.

5 Strategies

The strategies to address risks imposed by the surge arresters on the Victorian transmission system include:

- Complete replacement of 90% of silicon carbide type of surge arresters (Of these, 100% of surge arresters carrying risk of high impact failure will be replaced) by 2020.
- Complete replacement of surge arresters in conditions C4 and C5 by the end of 2022.
- Where possible, coordinate the replacement of silicon carbide, C4 and C5 surge arresters with major station or plant replacement works.
- Commence investigation on the first generation porcelain housed metal oxide surge arresters for condition deterioration.
- Investigate the economic viability of implementing an online condition assessment program to benchmark the condition of metal oxide surge arresters.

6 Appendices

6.1 Appendix A – Surge Arresters by Manufacturer

Figure 8 represents the surge arrester population by manufacturer.

[C.I.C]

Figure 8 – Surge Arrester population by Manufacturer