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RESPOND – I_s LIMITER SAFETY JUSTIFICATION

ISSUE 1.1

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Electricity North West Ltd

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GLOSSARY

ALARP	As Low As Reasonably Practicable
AP	Adaptive Protection
BM	Balancing Mechanism
CB	Circuit Breaker
CT	Current Transformer
DC	Direct Current
DNO	Distribution Network Operator
ENA	Energy Networks Association
ETA	Event Tree Analysis
FCL	Fault Current Limiting
FLAT	Fault Level Assessment Tool
FLMT	Fault Level Mitigation Technique
HAZOP	Hazard and Operability
HV	High Voltage
HSE	Health and Safety Executive
H&S	Health and Safety
IPCT	Interposing Current Transformer
LCNF	Low Carbon Network Fund
LV	Low Voltage
NAFIRS	National Fault and Interruption Reporting Scheme
NMS	Network Management System
Ofgem	Office of Gas and Electricity Markets
OHL	Overhead Line
QRA	Quantitative Risk Assessment
SDRC	Successful Delivery Reward Criteria
SFAIRP	So Far As Is Reasonably Practicable
SIL	Safety Integrity Level
SIPS	System Integrity Protection Scheme

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EXECUTIVE SUMMARY

Electricity North West's Respond project is trialling new methods of mitigating fault level issues as alternatives to expensive replacement of equipment. The Respond project is a Low Carbon Network Fund (LCNF) Tier 2 project, which is funded by the Low Carbon Innovation Fund.

One of these methods is the installation of an I_s Limiter which detects the onset of a fault condition and acts as an extremely fast switching device to reconfigure the circuit before the fault current exceeds the normal ratings of any of the equipment. Hence, it protects the equipment from being overloaded under fault conditions even though the prospective fault current without the I_s Limiter installed might have exceeded equipment ratings.

This safety justification is required to satisfy the LCNF project's Successful Delivery Review Criteria. It has been produced by WSP, independently from Electricity North West, with input from and peer review by other DNO(s) and presented to HSE to demonstrate that a robust approach has been taken.

A safety assessment has been undertaken to develop this safety justification for the implementation of the defined I_s Limiter scheme within the Electricity North West network. Key outcomes of the safety assessment are summarised below.

The safety assessment has categorised substation sites as low, medium or high risk to assign a range of measured safety requirements. In simple terms low risk sites are rural and not densely populated, medium risk sites are typical urban locations and high-risk sites are in continuously busy, densely populated areas. The analysis has shown that, based on arguably conservative assumptions, it would be acceptable from a safety viewpoint to fit substations with an I_s Limiter system if they are not very high-risk sites (i.e. sites with a risk above the median figure assumed for high risk sites).

The safety assessment process has determined four hazard scenarios presenting the most significant risk. These are: -

a) Short circuit of the busbar in a substation resulting in excessive fault current

b) Short circuit within a Circuit Breaker in the substation resulting in excessive fault current

c) Short circuit of the feeder cables or something connected to these cables such that the feeder cable withstand current is exceeded

d) Short circuit of the overhead line or something connected to the overhead line such that the overhead line withstand current is exceeded

These hazards only represent a hazard to personnel if the fault energy is not adequately contained and results in effects such as ground disruption due to cable failure, overhead line conductors clashing and falling to the ground, or fire and structural damage to substations. In these cases, the hazards could potentially result in injuries and fatality to workers and members of the public.

Safety requirements have been established (further to those already in place for the existing network and operations) which would ensure control of the risk associated with each of these scenarios to a 'Tolerable' level. The safety requirements include:

a) Application conditions that must be satisfied before applying I_s Limiter to a site, i.e. pre-requisites

b) Safety function and performance measures necessary for the I_s Limiter system, including safety integrity level (SIL 3)

c) Implementation, operating and maintenance measures necessary to control safety risk of the I_s Limiter scheme in use, including compliance with safety management systems, standards, procedures and codes of practice.

The study has also reviewed the requirements laid down by the health and safety applicable legislation. This identified 'absolute' requirements of the Electricity At Work (EAW) Regulations, specifically Regulations 5, 11 and 12 which, unlike other legislation requirements, are not satisfied by 'reasonably practicable' risk control measures and safety arguments. The EAW Regulations, Regulation 29, sets out the means for a legal defence in the event these 'absolute' regulations are breached.

This point has been discussed with HSE and the HSE's view was that provided a risk assessment had been performed which justified that the risk presented by the I_s Limiter scheme was 'Broadly Acceptable' then this would support an Electricity North West claim that it had taken sufficient steps to comply with the Regulations.

The safety assessment study has therefore considered steps that could be taken by Electricity North West to demonstrate that risks associated with the defined I_s Limiter scheme are 'Broadly Acceptable' for all scenarios.

By ensuring that substation structures and cable routes are able to contain the effects of fault energy release at very high-risk sites so that the risk becomes lower than the median for such sites, the risk associated with the scenario would then become 'Broadly Acceptable'.

1 INTRODUCTION

1.1 INTRODUCTION

Electricity North West commissioned WSP to assess the safety of the three Fault Level Mitigation (FLM) techniques being trialled by their Respond project and to assess compliance of the techniques with the relevant UK legislation.

WSP has prepared this Safety Justification independently as part of an unbiased and robust approach to assess the safety of the Respond FLM techniques.

1.2 THE RESPOND PROJECT

The prospective amount of current that will flow in an electrical network when a short circuit fault occurs is referred to as the fault level and it is an important parameter in the definition of power equipment capabilities. Network fault levels are increasing above the rating of some existing equipment due to the connection of distributed generation and changes in network topology.

Electricity North West's Respond project[1] is trialling new methods of mitigating fault level issues as alternatives to expensive replacement of equipment. The Respond project is a Low Carbon Network Fund (LCNF) Tier 2 project, which is funded by the Low Carbon Innovation Fund. Comprehensive project information can be obtained from the Respond website.

The Respond project aims to demonstrate the use of three innovative fault level mitigation (FLM) techniques which have not been previously used by a Distribution Network Operator (DNO) in the UK, namely;

- I_s Limiters (essentially an extremely fast acting switching and fuse device which senses the fault current rise and reconfigures the circuit to reduce the fault current)
- Adaptive Protection (AP) (a system whereby one out of two transformers in a substation is rapidly disconnected to reduce the subsequent fault current so that by the time other breakers trip they will not see excessive current)
- Fault Current Limiting service (FCL service) (a system whereby an external customer's site that contains generators or motors that could act as a fault current feed is rapidly disconnected to reduce the subsequent fault current so that by the time other breakers trip they will not see excessive current)

1.3 REQUIREMENT FOR SAFETY JUSTIFICATION

The FLM techniques being trialled by the Respond project, including I_s Limiter, can introduce changes to the way existing equipment is operated. A safety justification assesses the changes to provide a clear and comprehensive argument that the proposed application of each FLM technique is or is not acceptably safe.

The Respond project's safety justifications are required to satisfy the Successful Delivery Review Criteria, SDRC 9.3.8, as detailed below:

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[1] http://www.enwl.co.uk/respond/about-respond/what-is-respond-

Criteria	Evidence
Write Safety Case for each fault level mitigation technology deployed	Publish peer reviewed Safety Cases on the Respond project website by September 2018

The SDRC uses the term ‘safety case’. The Health and Safety Executive (HSE) views a safety case as a document associated with a licensing requirement to do work, such as in the nuclear industry. The HSE review such safety cases and may grant approval. In these terms, a safety case is not necessary for the use of the Respond project’s FLM techniques because the techniques are not licensed and HSE permission does not need to be granted. However, Electricity North West are committed to safety and as part of their safety processes they will produce a safety justification for the approach and this is presented here in the form of a safety case even though it is not part of a licence requirement.

Safety justifications for the Respond project have been produced by WSP, independently from Electricity North West, with input from and peer review by other DNO(s) and presented to HSE to demonstrate that a robust approach has been taken.

Three safety justifications will be prepared by WSP, one for each of the three FLM techniques being trialled by the Respond project, to assess their safety and compliance with Applicable Laws insofar as these Applicable Laws relate to health and safety (H&S Applicable Laws).

This safety justification report covers the I_s Limiter FLM technique. This safety justification is concerned with the safety of people, including the general public, through operation and maintenance. It does not specifically address the other aspects of the lifecycle (e.g. the manufacture, storage and disposal of the devices) or other risk categories (environmental, asset, reputation, etc.). It does not address failure to supply (i.e. compliance with Electricity North West’s Electricity Distribution Licence) or the environmental impact of incorrect operation.

The AP technique and the FCL service FLM technique are addressed in separate reports.

1.4 SAFETY JUSTIFICATION PROJECT

Figure 1-1 depicts the tasks undertaken to complete the safety assessment project.

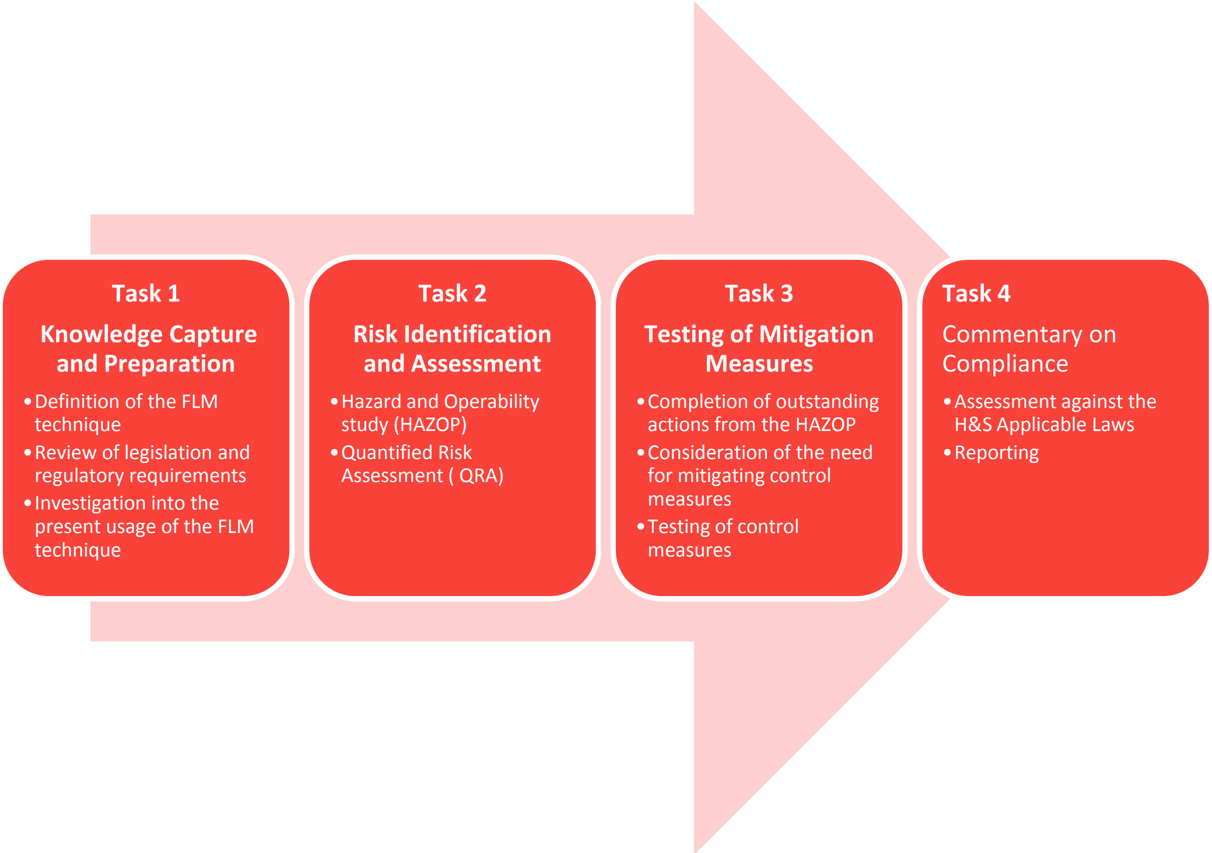


Figure 1-1 Respond Safety Justification Project Tasks

1.5 REPORT STRUCTURE

This report describes the process that has been followed to assess the safety of the use of an I_s-Limiter in distribution networks and presents the results along with the conclusions and implications arising from those results. It comprises the following sections;

Section 1	this introduction, provides the scope of the study and overview of the report structure;
Section 2	describes the safety assessment methodology that has been followed;
Section 3	defines I_s Limiter for the purpose of this safety assessment;
Section 4	explains the tolerability of risk framework and derivation of targets for this I_s Limiter scheme
Section 5	provides details of the review of applicable health and safety laws undertaken;
Section 6	details result and findings of the hazard identification and quantified risk assessment with discussion of results, comparison with requirements and sensitivity to changes;
Section 7	draws out conclusions and the implications of the safety assessment; and suggests further steps in the development of an I_s-Limiter scheme.

Appendices present detail from analysis, including hazard list, QRA and safety requirements

2 SAFETY ASSESSMENT APPROACH

A review undertaken at the start of this study has shown there are numerous previous installations of I_s-Limiters, like that proposed on the UK distribution network, in many countries as listed in Section 3 of this report. However, we have been unable to find a formal safety case for these applications and, in any case, the differences between UK law and that in other countries would make any such case only partly relevant. Therefore, we have produced this safety case without reference to other previous safety justifications except that we have been in collaboration with ABB who have been involved in many of the current applications.

The approach to assessment and justification of safety related systems in the UK generally is well understood and has been adopted for this study. This section describes the approach and the steps taken, as outlined in Figure 2-1, including wider management and supporting activities to ensure the quality and completeness of the final safety justification.

2.1 REVIEW OF LEGISLATION AND REGULATORY REQUIREMENTS

The first step of the assessment determines the legislative and regulatory framework applying to the installation of an I_s-Limiter. This defines constraints and key requirements, which the installation must comply with. The remaining steps in the safety assessment approach are tailored to address these requirements.

For most safety related applications, the most relevant legislation is the Health and Safety at Work Act 1974[2] (HSW Act) which adopts a risk based approach, specifying that risks should be reduced So Far As Is Reasonably Practicable (SFAIRP). This essentially means weighing the risk presented by an I_s-Limiter installation against the trouble, time and money needed to control that risk. Thus, I_s-Limiter risks would be expected to be controlled SFAIRP.

Other legislation applies to the use of an I_s-Limiter, such as the Electricity at Work Regulations (EAWR) 1989. This legislation includes requirements which are absolute rather than risk based. For example, EAWR Regulation 5 requires that no electrical equipment shall be put into use where its strength and capability may be exceeded in such a way as may give rise to danger. If an I_s-Limiter is installed in a scenario where the fault current would exceed the circuit breaker rating, should the I_s-Limiter fail to operate, then it could be interpreted that this is in contravention of Regulation 5.

Therefore, in conducting a review of the legislation and regulatory requirements, it is essential to consult with other industry stakeholders and particularly with HSE to establish their view as to the requirements arising from applicable H&S Laws and whether the installation of an I_s-Limiter can meet those requirements.

Findings of the review of H&S applicable laws are presented and discussed in Section 5.

Since the I_s-Limiter contains a small amount of explosive to operate it might be thought that the Explosives Regulations 2014 would apply. However, ABB have confirmed that because the amount of explosive is so small and the explosion is contained within the device itself their

[2] http://www.legislation.gov.uk/ukpga/1974/37/contents

devices are exempted from the regulations and do not pose a risk to personnel. This issue would need reviewing in the event of another manufacturers product being employed.

2.2 ESTABLISHING RISK CRITERIA

To determine whether the installation of an I_s-Limiter presents a ‘Broadly Acceptable’ or ‘Tolerable’ risk in accordance with legislation (SFAIRP and ALARP principles) it is necessary to establish appropriate risk tolerability criteria.

The study has investigated industry practice, consulted with Electricity North West and used guidance from HSE’s ‘Reducing Risk Protecting People’ publication to establish appropriate risk criteria for use with the Respond project.

Findings are presented and discussed in Section 4.

2.3 SAFETY ASSESSMENT METHOD

The safety justification considers safety, health and welfare issues associated with the use or failure of the I_s Limiter and preparation of a critical risk assessment. It is based on the specific application of the I_s Limiter being trialled and extrapolates to consider some options for implementation.

The overall process is summarised in Figure 2-1 below and each stage of the process is then briefly described.

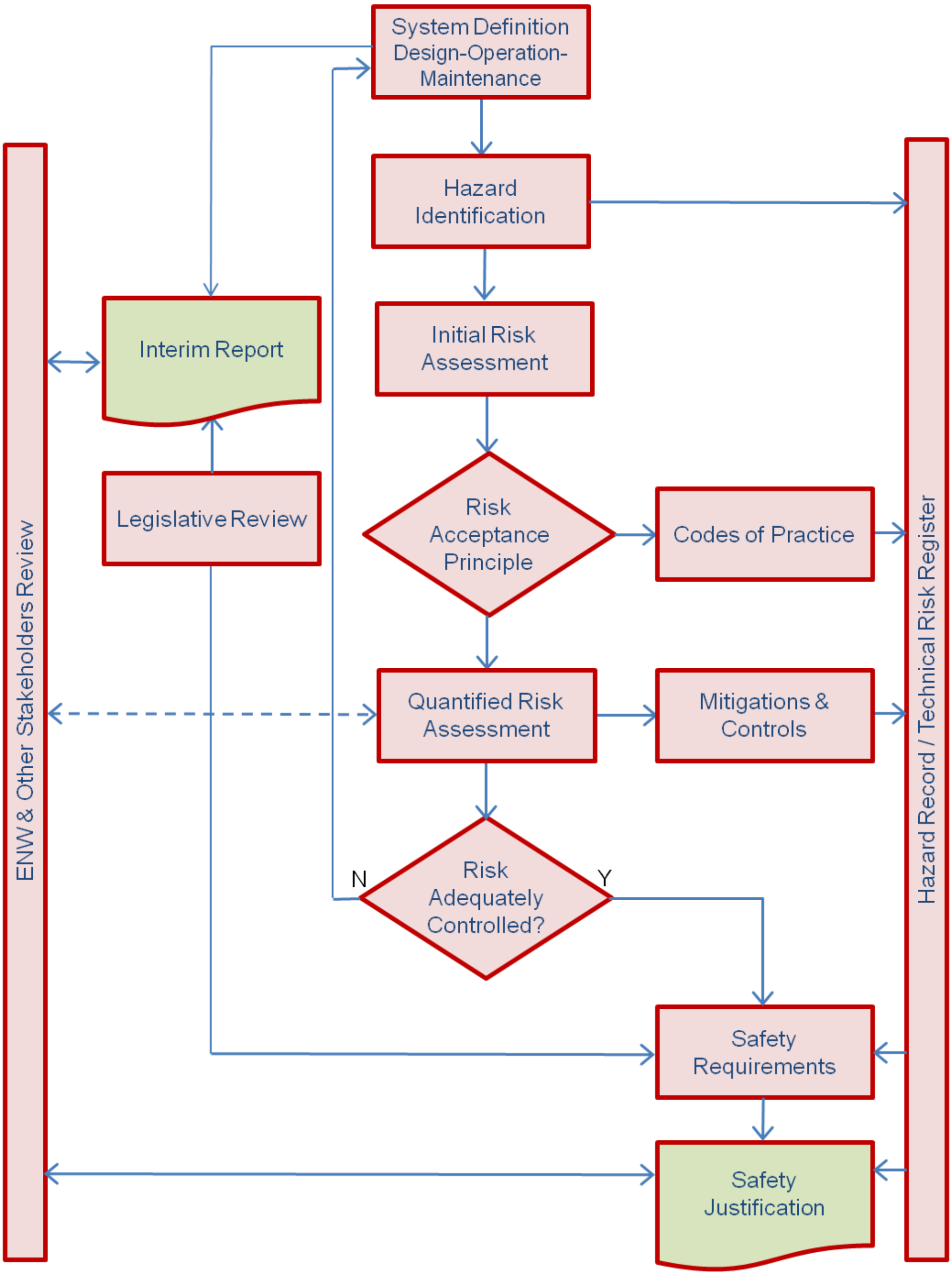


Figure 2-1 Respond Project Safety Assessment Process

2.4 SYSTEM DEFINITION

The system definition (Section 3) was based on a reference system with many alternatives. This formed the basis for the remainder of the analysis.

2.5 HAZARD IDENTIFICATION

A Hazard and Operability (HAZOP) workshop was conducted for the I_s Limiter based on the reference system described in Section 3. Identified hazards are presented in Section 6.1 with further detail in Appendix A. It should be noted that following review of the workshop output one further hazard was identified and added to the HAZOP record.

2.6 INITIAL RISK ASSESSMENT

An initial risk assessment was conducted during the HAZOP and was based on the engineering judgement of those present regarding frequency and consequence of the hazards.

2.7 RISK ASSESSMENT PRINCIPLE

Where a particular risk can be controlled purely by adherence to existing standards or regulations the “code of practice” principle was used. Where such a code of practice did not exist the Quantified Risk Assessment (QRA) principle was used.

2.8 CODES OF PRACTICE

Where codes of practice were applicable they were identified and conformance to them became the justification for safety.

2.9 QUANTIFIED RISK ASSESSMENT

Risk associated with some hazards could not be satisfactorily controlled through the application of codes of practice. Therefore, in these cases a quantified risk assessment (QRA) has been undertaken. The QRA has determined where further control measures have been required to satisfactorily reduce that risk. The QRA and findings are presented and discussed in Sections 6.2 to **Error! Reference source not found.** with supporting calculations at Appendix B.

2.10 SAFETY REQUIREMENTS

Results from the HAZOP and QRA and from review of the H&S applicable laws have determined safety requirements and conditions necessary for the installation of an I_s Limiter.

The safety justification includes statements and evidence to support where each safety requirement is achieved by the implementation of the I_s Limiter defined in Section 3. The safety justification also suggests improvements to the defined I_s Limiter where this is necessary to achieve a safety requirement.

Safety requirements arising from the HAZOP and QRA are discussed in Section 6.8 and presented in Appendix C.

2.11 PROJECT SAFETY ORGANISATION

The project safety organisation depicts Electricity North West's role as owner of the safety justification, WSP as independent producer of the safety justification and the involvement of other stakeholders in the consultation and review process, as shown in Figure 2-2.

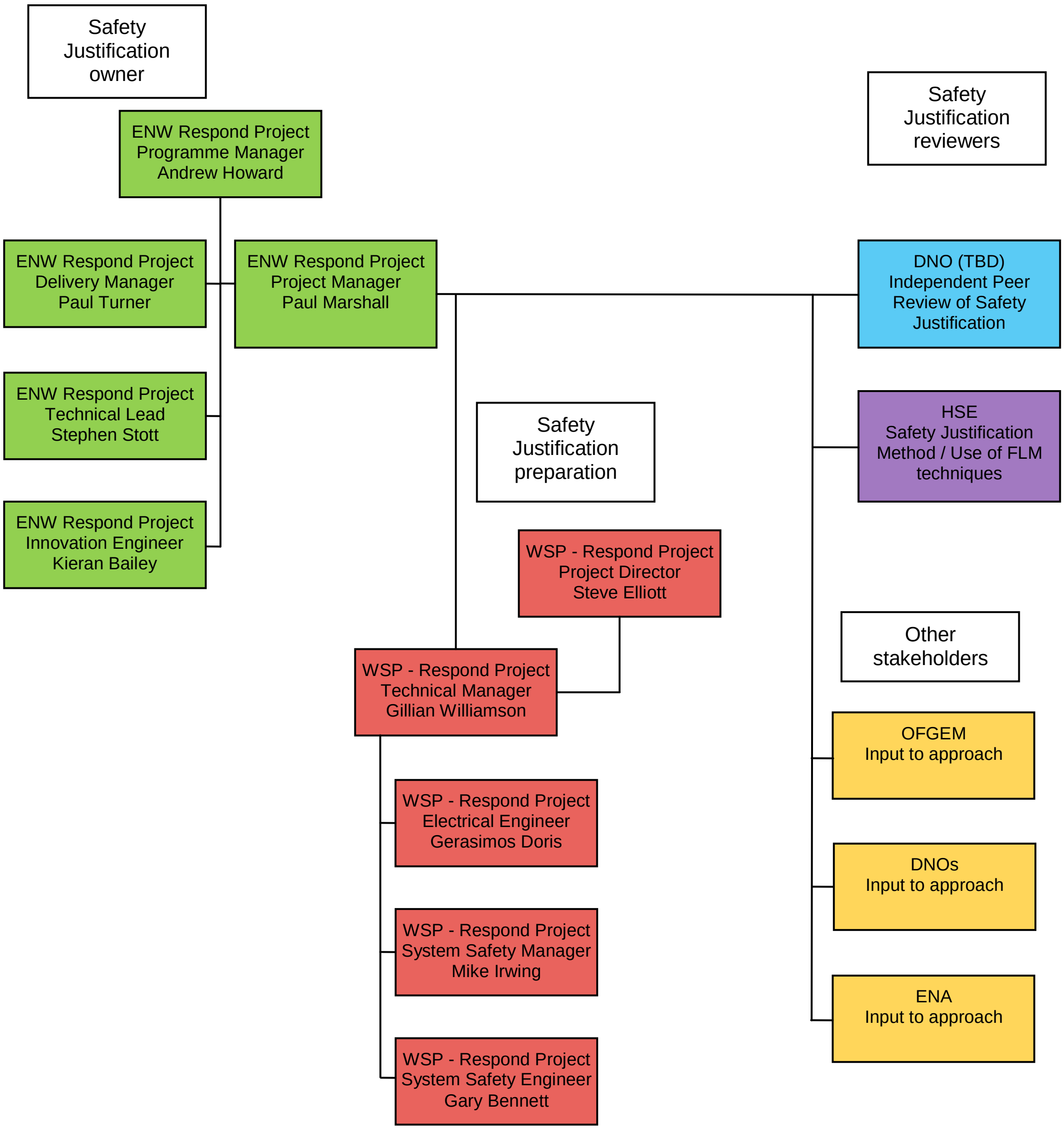


Figure 2-2 Safety Justification delivery and responsibility organisation

2.12 MANAGEMENT, REVIEW AND APPROVAL

The study has been undertaken in stages with interim findings being presented, documented and reviewed incrementally to ensure quality and validity of input data, assumptions and findings and to maintain focus on objectives.

Key review points included:

- An interim report presenting: a definition of a representative application of the I_s Limiter technique based on a trial site installation; H&S Applicable Legislation review findings
- HAZOP workshop output
- Meeting with HSE
- Quantified Risk Assessment presentation to Electricity North West at a meeting on 22nd January 2018
- Electricity North West review of Safety Justification report

In addition, it is anticipated that an independent peer review will be conducted by another UK DNO having knowledge of and involvement in similar projects.

3 I_S LIMITER

3.1 INTRODUCTION

Details of the I_s Limiter as it will be installed and operated when applied as part of business as usual are given in this section for the purposes of the safety justification. It was important to describe how the I_s Limiter will be realised and will function in order that the potential hazards relating to the specific conditions could be established, evaluated and mitigated as required. This safety justification relates to the definition of I_s Limiter given here.

It should be noted that the realisation of the I_s Limiter described may be marginally different than the installation for the Respond trials because of slightly different requirements. Fault levels do not exceed the equipment's rating at the trial sites and therefore there was no need for a safety case before the trial commenced.

This safety assessment is based on experience gained from the I_s Limiters currently being trialled on the 11/6.6kV networks at Bamber Bridge and Broad heath primary substations and consequently does not cover the installation of I_s-Limiters on 33kV networks.

A Fault Level Assessment Tool (FLAT) incorporated into Electricity North West's Network Management System has been developed as part of the Respond project. It assesses the network fault levels and has been considered as a method to control the enablement of the FLM techniques. However, it has been concluded, based on the trial findings, that the FLAT will not form part of the business as usual approach for the application of the I_s Limiter initially. Therefore, this definition of the I_s Limiter does not include FLAT functionality and it is taken to be permanently enabled for the purposes of this assessment. This safety assessment would need to be reviewed should enablement via the FLAT be subsequently incorporated into the I_s Limiter.

3.2 DEFINITION

3.2.1 Installation

With the I_s Limiter the network is reconfigured to reduce the fault current before the network circuit breaker controlling the faulty section of network is opened to clear the fault.

An I_s Limiter is a combination of an extremely fast acting switching device, which can conduct a high current but has a low switching capacity, and a fuse with a high breaking capacity mounted in parallel. In order to achieve the desired short opening time a small explosive charge is used as a stored energy mechanism to interrupt the switch (main conductor). When the main conductor has opened, the current still flows through the parallel fuse which operates within 0.6ms to limit the prospective fault current (i.e. during the first quarter cycle before the short circuit current reaches its full value) and then finally interrupts it at the next voltage zero.

For the application of the I_s Limiter installed in series with a transformer incomer 11(6.6)kV CB (Type A) or in parallel with bus section 11(6.6)kV CB (Type B) the standard configurations are shown in Figure 3-1 and Figure 3-2, respectively.

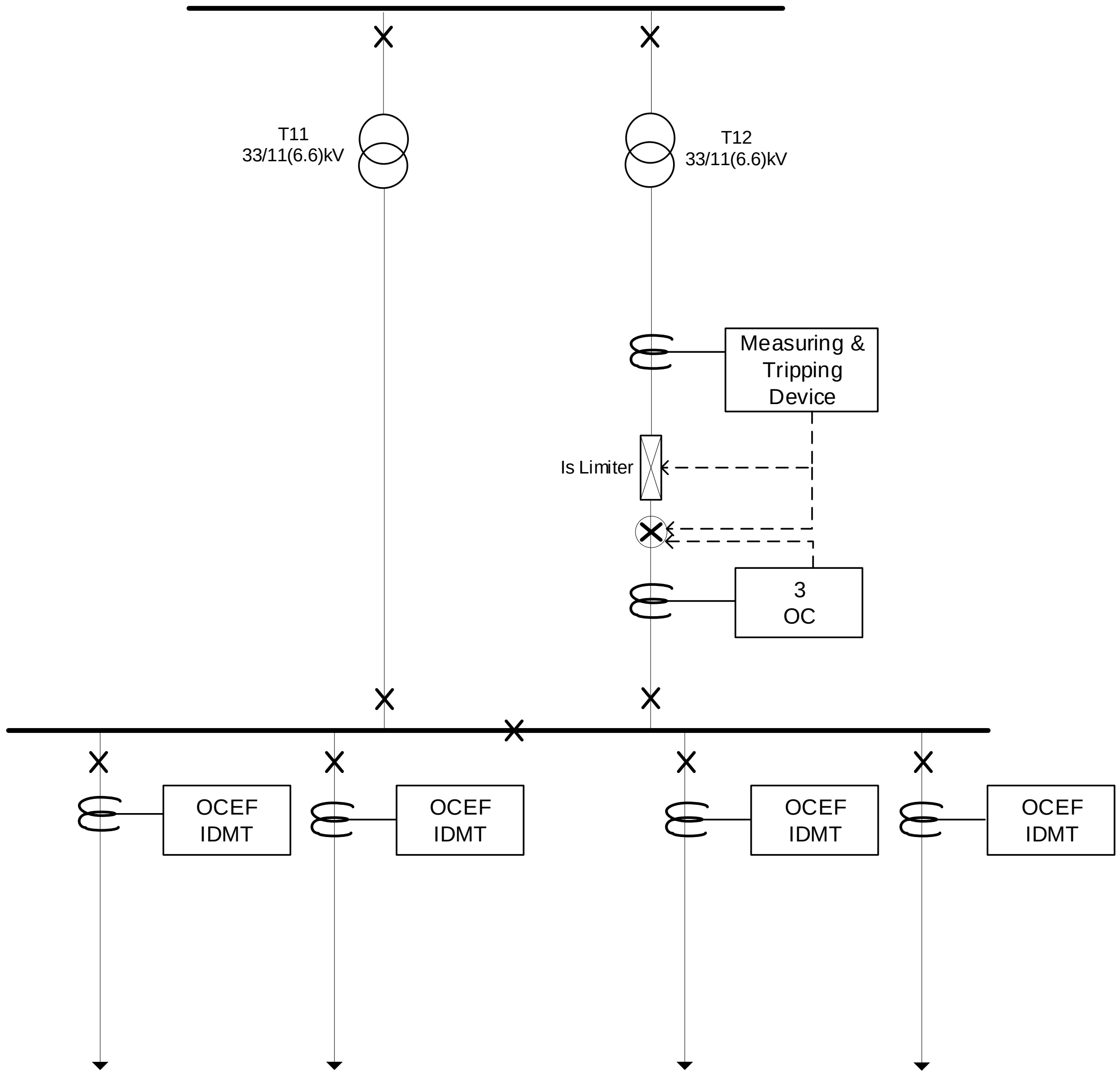


Figure 3-1 Standard I_s Limiter Installation A-type

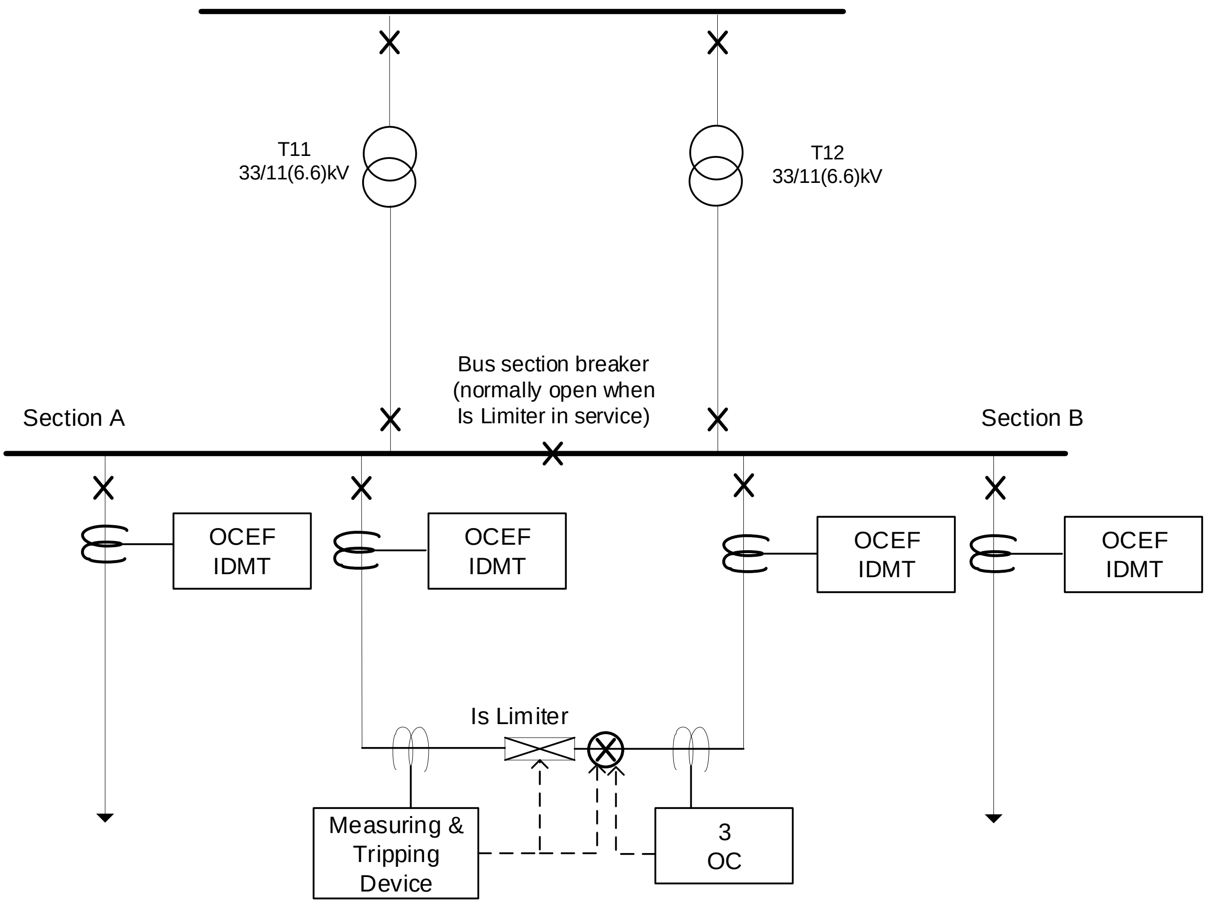


Figure 3-2 Standard I_s Limiter Installation B-type

3.2.2 Operation

3.2.2.1 I_s LIMITER IN SERIES WITH A TRANSFORMER INCOMER 11(6.6)KV CIRCUIT BREAKER – TYPE A

For Type A installations, the I_s Limiter is installed in series with a transformer 11(6.6)kV circuit breaker.

The I_s Limiter is provided with an associated series circuit breaker as shown in Figure 3-1.

The current flowing through the I_s Limiter is monitored by an electronic measuring and tripping device. A trip occurs as soon as an impermissibly high short-circuit current begins to flow. In order to determine whether tripping of the I_s Limiter is necessary, the instantaneous current and rate of rise of current across the I_s Limiter are constantly measured and evaluated.

The I_s Limiter series circuit breaker is normally tripped by the I_s Limiter but it also has its own CT's and protection relay. This relay trips the I_s Limiter series circuit breaker if it detects a phase current above the current setting threshold (the earth fault element is not enabled). It performs this trip almost instantaneously (minimum time delay setting of 20ms), which means it will issue a trip command in about 40ms.

If the I_s Limiter operates correctly it will interrupt the fault current in the faulted phase/s and trip the series circuit breaker before the I_s Limiter series circuit breaker protection relay can respond.

Following an I_s Limiter trip, the insert(s) that have operated must be replaced before it can be restored to the service position.

3.2.2.2 I_s LIMITER IN PARALLEL WITH BUS SECTION 11(6.6) kV CIRCUIT BREAKER – TYPE B

For Type B installations, the I_s Limiter is installed in parallel with the bus section 11(6.6) kV circuit breaker.

The I_s Limiter is provided with an associated series circuit breaker and the combination is connected to a circuit breaker on each of the 11(6.6) kV busbar sections as shown in Figure 3-2.

The current flowing through the I_s Limiter is monitored by an electronic measuring and tripping device. A trip occurs as soon as an impermissibly high short-circuit current begins to flow. To determine whether tripping of the I_s Limiter is necessary, the instantaneous current and rate of rise of current through the I_s Limiter are constantly measured and evaluated.

The I_s Limiter series circuit breaker is normally tripped by the I_s Limiter but it also has its own CT's and protection relay. This relay trips the I_s Limiter series circuit breaker if it detects a phase current above the current setting threshold (the earth fault element is not enabled). It performs this trip almost instantaneously (minimum time delay setting of 20ms), which means it will issue a trip command in about 40ms.

If the I_s Limiter operates correctly it will interrupt the fault current in the faulted phase/s and trip the series circuit breaker before the I_s Limiter series circuit breaker dedicated protection relay can respond.

When the I_s Limiter is in service, the bus-section 11(6.6) kV circuit breaker is open so that any transformer fault current flowing from one section of busbar to the other section will pass through the I_s Limiter.

Following an I_s Limiter trip, the insert(s) that have operated must be replaced before it can be restored to the service position.

3.2.3 Network Conditions

The Type B application was the one analysed in the Hazard Workshop as it was believed to be the more likely to be used application. For the Type B application the I_s Limiter will only be employed in networks when all the following network conditions are met:

i. An alarm/warning system exists in the central Control Room to indicate an I_s Limiter problem (see safety requirement 7)

ii. The prospective fault current at existing customer's switchgear on any feeder is within its rating or the fault level at a customers' site is equal to or less than the design fault level, even if the I_s Limiter fails to operate. (See Safety requirement 16)

iii. Transformer fault currents are within the rating of the transformer and its circuit breaker even if the I_s Limiter fails to operate. (see safety requirement 20)

For the Type A application the same application conditions would apply except that for the transformer with the Is Limiter in series the fault current only needs to be within the rating if the Is Limiter correctly operates.

3.2.4 Maintenance

Existing maintenance procedures and scheduling for two-transformer sites such as Bamber Bridge have been assumed to be in use. Table 3-1 shows the inspection and maintenance intervals for I_s Limiters.

Table 3-1 I_s Limiter inspection and maintenance intervals

I_s Limiters		
	Period in Months	**Notes**
I_s- Limiter switchboard	48	Inspections as detailed in section 7.2 of ABB I_s-Limiter instruction manual BA 323/04 E.
I_s Limiter tripping device and interlocks	12	The I_s-Limiter electronics are tested in conjunction with a proprietary test insert. Refer to sections 7.2.1 and 7.3 of ABB I_s-Limiter instruction manual BA 323/04 E.
I_s Limiter inserts	96	Inserts installed in active I_s-Limiters must be returned to the ABB factory for refurbishment within 8 years.
	144	Inserts in storage must be returned to the ABB factory for refurbishment within 12 years.

3.3 EXISTING USAGE

Previous and existing use of the I_s Limiter would be a useful source of information for producing a safety justification for this Electricity North West application. WSP therefore performed a thorough search regarding existing applications which concluded that this specific concept is not unique, but rather well established in other countries and on UK industrial sites.

I_s Limiters are installed in many countries on Utility related networks and industrial sites. They are used in more than 2,500 stations in 70 countries[3]. Some of the companies that use I_s Limiters for fault current limiting purposes include:

- Enel – an Italian multinational energy company, generating energy, selling gas and distributing electricity across a network spanning approximately 2.2 million km.
- ENMAX Canada – a group of companies that generates, transmits, distributes and sells energy across Alberta.

[3] https://new.abb.com/medium-voltage/apparatus/fault-current-limiting/current-limiter/current-limiter-applications

- PPC Greece- the Public Power Corporation is the biggest power producer and electricity supply company in Greece. Currently holds assets in lignite mines, power generation, transmission and distribution.

- Dubai Electricity and Water Authority – a public service infrastructure utility company that supplies electricity and water to Dubai.

- Pacific Gas and Electric Company – one of the largest combined natural gas and electric energy companies in the US, based in San Francisco. Transmits and delivers energy in approximately 70,000 square-mile service area in northern and central California.

- China National Offshore Oil – China's largest producer of offshore crude oil and natural gas.

- Nuon Power Generation – part of the energy group Vattenfall, is an energy company that serves around 2 million consumers, companies and organizations in the Netherlands. Produces and supplies electricity, heat, cold and gas.

Up until the end of 2014 ABB have installed a total of 106 I_s Limiters in utility related applications and up until 2018 they have installed more than 500 in other applications worldwide.

3.4 REFERENCE SYSTEM

Although I_s Limiters are being trialled at multiple sites and will be installed in unknown locations as part of business as usual, the safety assessment takes as a starting point the installation on a single site agreed with Electricity North West. This approach has been adopted because it is considered that the development of the safety justification benefits from basing it on a specific installation. Using a specific installation allows all hazards to be visualised and the sensitivities of the installation to be considered. The process aims to identify the "worst credible case" examples and indicate the safety margins so that, as explained later in this report, the safety justification has been generalized to a wide range of potential applications.

The reference case for the basis of the safety assessment was chosen to be a two-transformer site at Bamber Bridge. The site's single line diagram is illustrated on Figure 3-3 as based on information given in Electricity North West's Long-Term Development statement[4].

[4] https://www.enwl.co.uk/secure-area/ltds-document-library

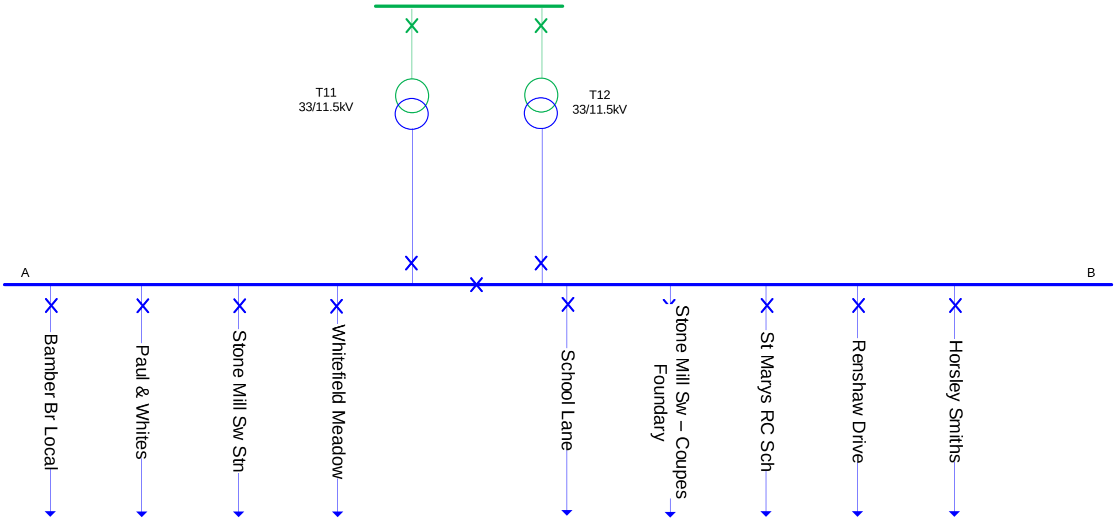


Figure 3-3 Bamber Bridge – single line diagram

The I_s Limiter has been implemented at Bamber Bridge as shown in Figure 3-4 as part of the Respond trial.

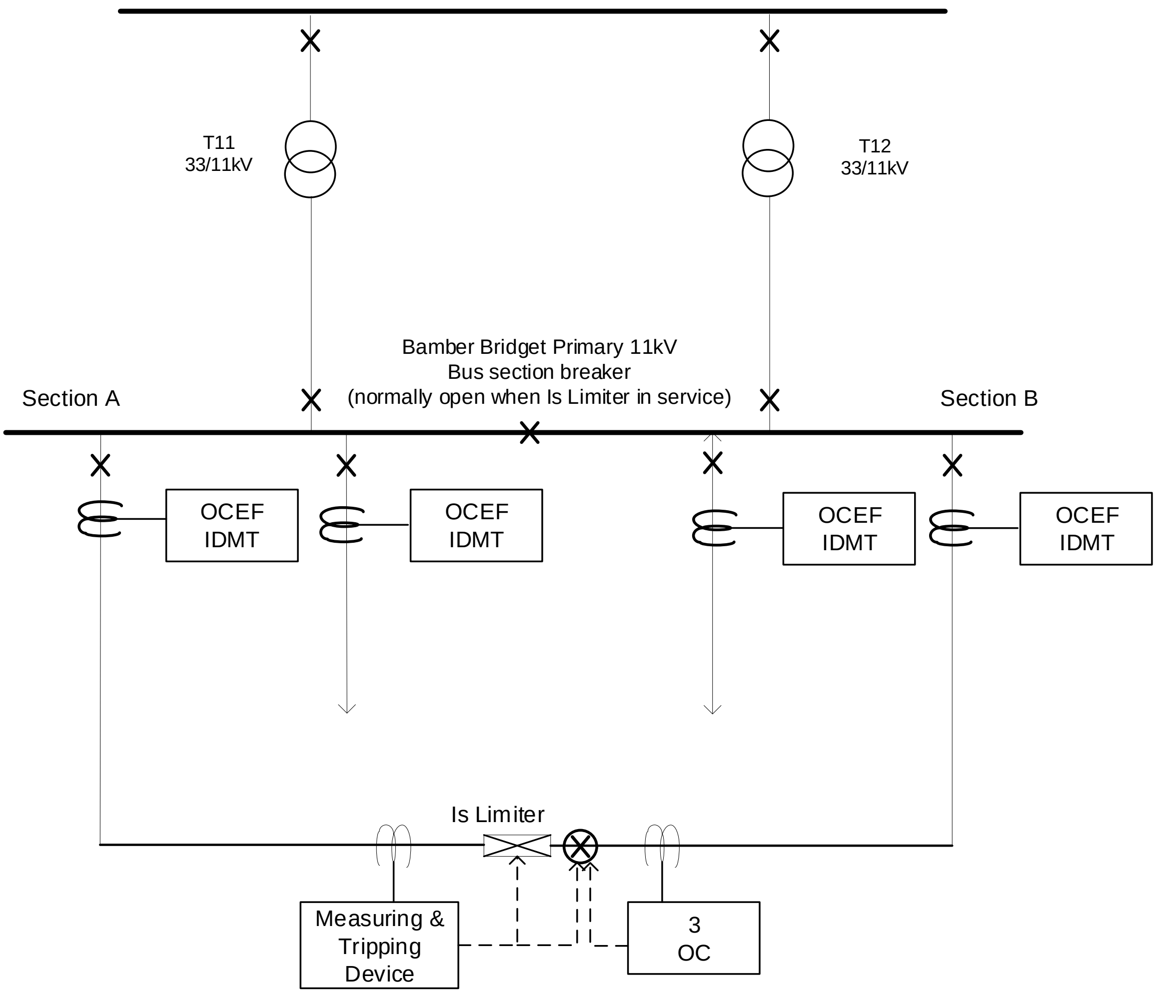


Figure 3-4 I_S Limiter – Bamber Bridge substation network

4 TOLERABILITY OF RISK FRAMEWORK

The standard framework for tolerability of risk is explained in the HSE publication Reducing Risks Protecting People (R2P2)[5].

R2P2 places risk into one of three regions: 'Unacceptable', 'Tolerable" and 'Broadly Acceptable'. These are depicted in Figure 4-1. As explained in Section 2.1 it is normally acceptable if risks in the tolerable region are reduced SFAIRP. However, in the case of an I_s Limiter, because it arguably contravenes Regulation 5, risks would need to be reduced to the "Broadly Acceptable" level.

Guidance in R2P2 has been used to determine the boundaries between the different regions.

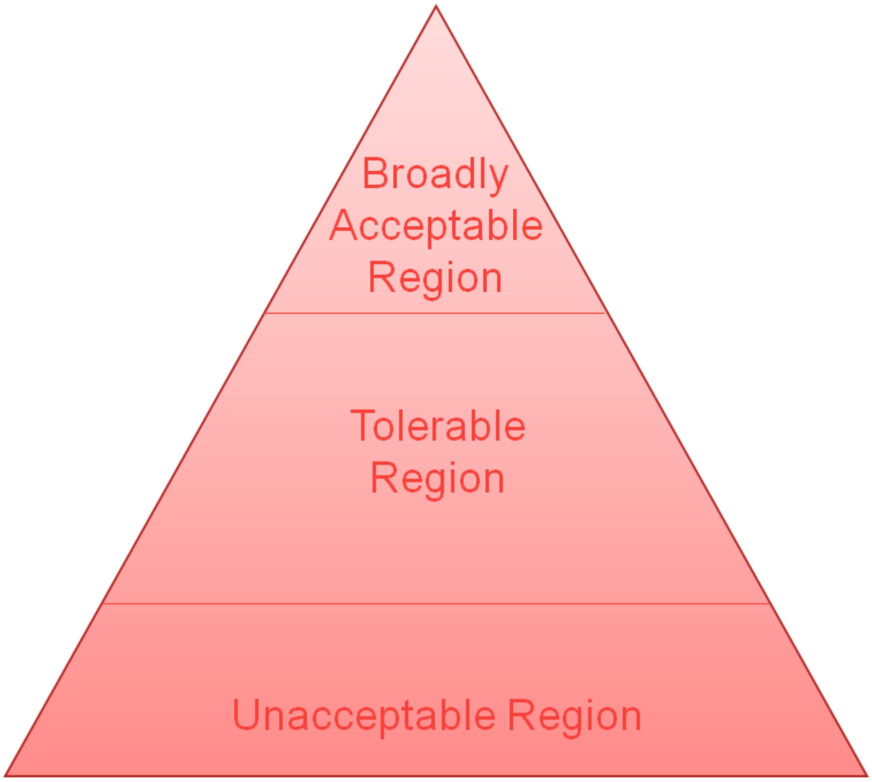


Figure 4-1 HSE framework for the Tolerability of Risk

The R2P2 guidance presents an upper tolerability limit for risk of death for an individual worker at 10^{-3} per annum and for an individual member of the public at 10^{-4} per annum.

The guidance also states that an individual risk of death at 10^{-6} per annum for both workers and the public corresponds to a very low level of risk and should be used as a guideline for the boundary between the 'Broadly Acceptable' and 'Tolerable' regions. The R2P2 tolerability limits for risk of death have been considered in the development of a risk framework for the Respond

[5] http://www.hse.gov.uk/risk/theory/r2p2.pdf

project to assess the use of each of the three FLM techniques (Adaptive Protection, I_s Limiter and Fault Current Limiting Service) on the Electricity North West electricity distribution network. A risk matrix for workers is presented in Table 4-1 and a risk matrix for the public is presented in Table 4-2 and these represent the summation of risk across Electricity North West from Respond schemes on a 'per hazard' basis. The individual risk is the probability for an exposed individual that they personally are killed or injured. Therefore, it is not the risk of a fatal accident but the risk to a specific individual being killed in that accident. For example, if there is one fatal accident that kills a substation worker per year and there are 50 substation workers the individual risk is 1 in 50 years.

The R2P2 boundary values correspond to all the risks faced by workers and the public, whilst the use of an I_s Limiter is only one of these risks. Consequently, the HSE guidance has been calibrated for the specific hazards due to the use of I_s Limiters and the resulting boundary conditions are shown in Figure 4-2 for a single substation site.

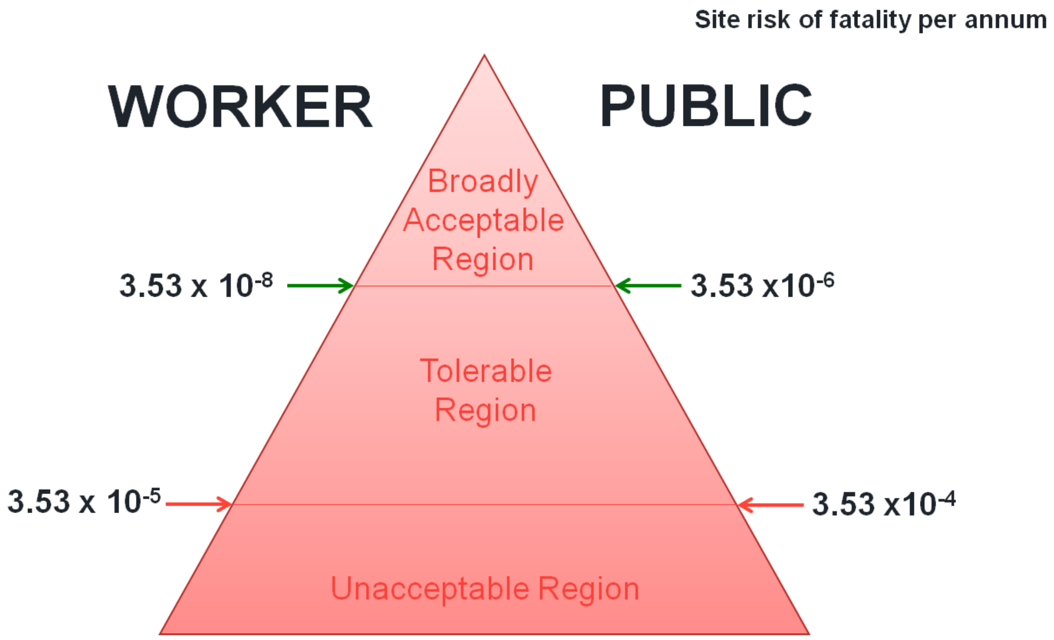


Figure 4-2 Specific Boundary values for RESPOND Project

These values can also be used as the basis for a matrix characterising the tolerability of risk presented by Respond hazards for workers (Table 4-1) and for the public (Table 4.2)

Table 4-1 Risk Matrix (per hazard) - Workers

	FREQUENCY (per annum)					
SEVERITY	6 Frequent $> 10^{-1}$	5 Likely $> 10^{-2}$ $<=10^{-1}$	4 Occasional $> 10^{-3}$ $<=10^{-2}$	3 Infrequent $> 10^{-4}$ $<=10^{-3}$	2 Remote $> 10^{-5}$ $<=10^{-4}$	1 Highly improbable $> 10^{-6}$ $<=10^{-5}$
5 Serious	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Tolerable	Tolerable
4 Significant	Unacceptable	Unacceptable	Unacceptable	Tolerable	Tolerable	Tolerable
3 Moderate	Unacceptable	Unacceptable	Tolerable	Tolerable	Broadly acceptable	Broadly acceptable
2 Minor	Unacceptable	Tolerable	Tolerable	Broadly acceptable	Broadly acceptable	Broadly acceptable
1 Negligible	Tolerable	Tolerable	Broadly acceptable	Broadly acceptable	Broadly acceptable	Broadly acceptable

Table 4-2 Risk Matrix (per hazard) – Public

SEVERITY	FREQUENCY (per annum) 6 Frequent $> 10^{-1}$	5 Likely $> 10^{-2}$ $<=10^{-1}$	4 Occasional $> 10^{-3}$ $<=10^{-2}$	3 Infrequent $> 10^{-4}$ $<=10^{-3}$	2 Remote $> 10^{-5}$ $<=10^{-4}$	1 Highly improbable $<=10^{-5}$
5 Serious	Unacceptable	Unacceptable	Unacceptable	Tolerable	Tolerable	Broadly acceptable
4 Significant	Unacceptable	Unacceptable	Tolerable	Tolerable	Broadly acceptable	Broadly acceptable
3 Moderate	Unacceptable	Tolerable	Tolerable	Broadly acceptable	Broadly acceptable	Broadly acceptable
2 Minor	Tolerable	Tolerable	Broadly acceptable	Broadly acceptable	Broadly acceptable	Broadly acceptable
1 Negligible	Tolerable	Broadly acceptable	Broadly acceptable	Broadly acceptable	Broadly acceptable	Broadly acceptable

The consequence classifications (severity) used in the Respond risk matrices are defined in Table 4-3. They are based upon the safety descriptors from a risk appetite framework used by Electricity North West to qualitatively assess and manage risks in key areas of its business including safety.

Table 4-3 Consequence classifications

LEVEL	CONSEQUENCE	SAFETY/HEALTH DESCRIPTOR
1	Negligible	Slight injury not requiring treatment.
2	Minor	First aid / medical treatment is required.
3	Moderate	Time losing injury / health impact results.
4	Significant	A fatality / fatal occupational disease occurs or multiple Moderate injuries.
5	Serious	Multiple fatalities / fatal occupational diseases occur.

Each risk matrix has been calibrated for the Respond project to account for the expected hazards, at-risk population and contribution to the overall Electricity North West risk profile using the following equations for the upper limit of tolerable risk, with parameters defined in Table 4-4. For the purposes of this calibration it was judged reasonable that if Respond was widely adopted it may constitute up to 2% of an overall workers risk. It was also assessed that Respond would introduce approximately 10 hazards based on the initial hazard identification.

Worker fatality (per Respond hazard) per annum $R_{WHT} = R_{IWT} \times P_{WRE} \times C_{PR} / H$

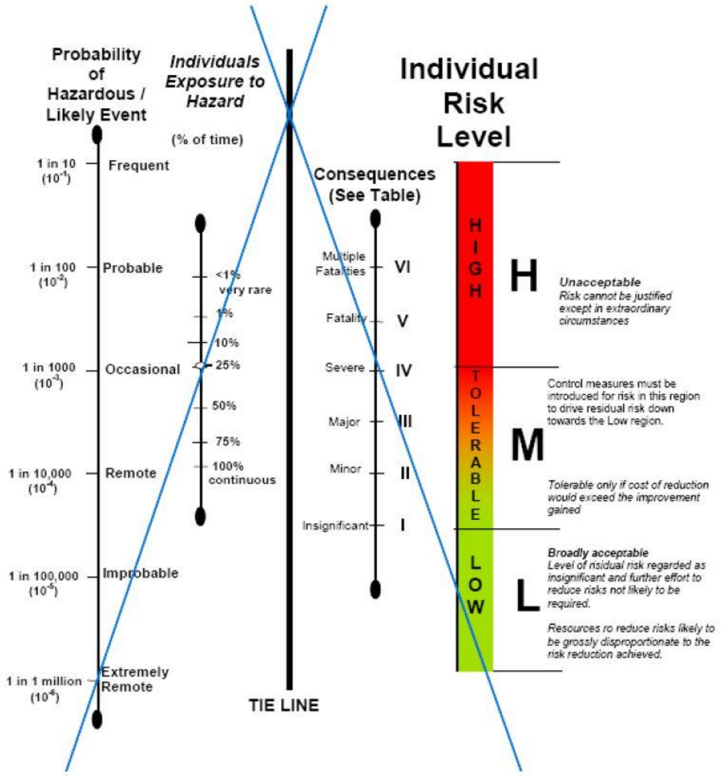
- Public fatality (per Respond hazard) per annum $R_{PHT} = R_{IPT} \times P_{PRE} \times C_{PR} / H$

Table 4-4 Risk matrix calibration

PARAMETER	VALUE	DESCRIPTION
R_{IWT}	10^{-3} per annum	Upper limit of tolerability for risk of death of individual worker per annum.
P_{WRE}	500	Worker population exposed to Respond hazards, assuming Electricity North West/customer workforce of 2000 of which 25% operates in vicinity of switchgear.
C_{PR}	0.02	Contribution of Respond risk as proportion of overall Electricity North West risk (i.e. 2%).
H	10	Estimated number of hazards associated with Respond project fault level mitigation techniques.
R_{WHT}	10^{-3} per annum per hazard	Upper limit of tolerability for risk of death from single hazard associated with Respond project, calculated using equation $R_{IWT} \times P_{WRE} \times C_{PR} / H$
R_{IPT}	10^{-4} per annum	Upper limit of tolerability for risk of death of individual member of the public per annum.
P_{PRE}	50,000	Public population exposed to Respond hazards, assuming

PARAMETER	VALUE	DESCRIPTION
		population density 0.0001 persons per m^2 in risk zone.
R_{PHT}	10^{-2} per annum per hazard	Upper limit of tolerability for risk of death from single hazard associated with Respond project, calculated using equation R_{IPT} x P_{PRE} x C_{PR} / H

Separately, the Energy Networks Association (ENA) has published guidance in its SHE Standard 07 Model Distribution Safety Rules (MDSR) which includes an approximation tool for risk assessment, refer to Figure 4-3. The derivation of the tool is not presented within the ENA standard; however, a comparison has been undertaken between the tool and the risk tolerability matrices (Table 4-1 and Table 4-2) used in this document. There is a general correlation of results from both schemes although the risk matrices used in this document appear slightly more cautious than the ENA MDSR risk assessment scheme.



Consequences		
VI	Multiple Fatalities	
V	Fatality	
IV	Severe	Permanent disability / loss of sight
III	Major	Serious injury (effects reversible)
II	Minor	Injury requiring medical treatment
I	Insignificant	Bruising / First Aid injury
Exposure to Hazard	(Based on working week of 5 X 8hr days)	
	per week	per day
0.5%	¾ hr	10 mins
1%	1.5 hrs	20 mins
2.5%	3 ¾ hrs	45 mins
5%	8 hrs	1 ½ hrs
7.5%	12 hrs	2 ½ hrs
10%	16 hrs	3 hrs
15%	24 hrs	5 hrs
20%	32 hrs	6.5 hrs
25%	40 hrs	8 hrs
50%	80 hrs	16 hrs
75%	120 hrs	24
100%	160 hrs	24 hrs

Figure 4-3 ENA risk assessment tool - extract from ENA SHE Standard 07 MDSR

5 LEGISLATIVE REVIEW

5.1 LEGISLATIVE FRAMEWORK

A review was conducted of H&S Applicable Laws and supplementary guidance relating to the implementation of an Adaptive Protective scheme in the UK. The review included:

- Health and Safety Work etc. Act 1974 (HSW Act)
- Management of Health and Safety at Work Regulations 1999
- Electricity at Work Regulations 1989 (EAW Regulations)
- EAW Regulations 1989 Guidance on Regulations HSR25 2015
- Electricity at Work: Safe Working Practices, HSG85, 2013
- Electricity Safety, Quality and Continuity Regulations 2002 (ESQC Regulations) with Amendments 2006 and 2009

Where significant requirements have been identified as applicable to changes introduced by the I_s-Limiter to the DNO assets and operations, these have been included in Appendix D.

5.2 DISCUSSION OF REQUIREMENTS

For safety related applications, such as the I_s Limiter scheme, the most relevant general legislation is the HSW Act which specifies that risks of injury associated with an undertaking shall be reduced 'So Far As Is Reasonably Practicable' (SFAIRP).

Similarly, the ESQC Regulations, particularly pertinent to the safety of design and implementation of an I_s Limiter scheme, require that the associated risks of injury shall be reduced SFAIRP.

Requirements based on the SFAIRP principle are achievable by developing and implementing an I_s Limiter scheme which is underpinned by a hazard identification and risk assessment process including demonstration that risks not 'Broadly Acceptable' are nevertheless 'Tolerable' and 'As Low As Reasonably Practical (ALARP)'.

The EAW Regulations, however, include three regulations conferring requirements upon an undertaking, such as the I_s Limiter scheme, which are construed as absolute requirements:

- Regulation 5 - *"No electrical equipment shall be put into use where its strength and capability may be exceeded in such a way as may give rise to danger"*[6]
- Regulation 11 - *"Efficient means, suitably located, shall be provided for protecting from excess of current every part of a system as may be necessary to prevent danger."*
- Regulation 12 – *"Where necessary to prevent danger, suitable means (including, where appropriate, methods of identifying circuits) shall be available for: (a) cutting off the supply of electrical energy to any electrical equipment; and (b) the isolation of any electrical equipment."*

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[6] In the EAW Regulations "danger" means risk of injury

HSR25, HSE guidance on the EAW Regulations, is particularly relevant to the installation of an I_s Limiter and provides clear interpretation of the meaning of the terms used in the regulations and of the purpose of each regulation.

HSR25 clause 58 states:

> *"If the requirement in a regulation is 'absolute', for example if the requirement is not qualified by the words 'so far as is reasonably practicable', the requirement must be met regardless of cost or any other consideration. Regulations making such absolute requirements are subject to the defence provision of regulation 29."*

Appendix D cites several extracts from the HSR25 guidance associated with Regulations 5, 11 and 12 where the extracts explain the relevant requirements and how the 'absolute' and 'reasonably practicable' terms apply.

Regulations which contain 'absolute' requirements are therefore unequivocal.

I_s Limiters are intended for use in cases where fault levels would potentially exceed equipment capability. If an I_s Limiter was to be installed in a case where the fault current could exceed the circuit breaker rating then, should the I_s Limiter fail, it may be interpreted as being in contravention of EAW Regulations 5, 11 and 12.

HSE expressed the view, when consulted about this specific point, that failure of an I_s Limiter would contravene these regulations and that the defence against prosecution, in accordance with Regulation 29 of the EAW Regulations, would be that a person or organisation (i.e. Electricity North West) would need to prove that it had taken all reasonable steps and exercised due diligence to avoid commission of an offence against the Act. In the view of HSE this would be satisfied if any risks were shown to be "Broadly Acceptable" and hence the normal SFAIRP argument would not apply.

6 HAZARD IDENTIFICATION AND QUANTIFIED RISK ASSESSMENT

This section documents the hazards identified as associated with the I_s Limiter scheme and presents the results of the risk assessment conducted to determine the level of risk presented by the scheme.

6.1 IDENTIFIED HAZARDS

The HAZOP exercise identified four hazards that represent a significant potential risk to workers on or close to the substations where the I_s Limiter is installed and to members of the public in close proximity to the affected substations or transmission cables. These are:

e) Short circuit of the busbar in a substation resulting in excessive fault current

f) Short circuit within a Circuit Breaker in the substation resulting in excessive fault current

g) Short circuit of the feeder cables or something connected to these cables such that the feeder cable withstand current is exceeded

h) Short circuit of the overhead line or something connected to the overhead line such that the overhead line withstand current is exceeded

For each of these hazards a quantified risk assessment has been conducted.

A further 37 hazards were identified which presented no significant change to the situation existing without I_s Limiter installed. The complete list of hazards is included at Appendix A.

6.2 QRA METHODOLOGY

Event Tree has been used as the QRA methodology. This starts with the initiating event (e.g. feeder cable short circuit) and then considers how this can develop into a range of possible outcomes including fatality and other accident scenarios. In general, the Event Tree for each hazard progresses with the I_s Limiter failure resulting in an explosion and then with either a worker or a member of the public in critical proximity they are killed by the explosion.

By considering the frequency of the initiating event and the probabilities of each of the subsequent steps in the accident chain the overall frequency of accidents is calculated.

6.3 INPUT DATA

6.3.1 Frequency of Initiating Events

The frequency of each of the initiating events has been estimated using available data as summarised in Table 6.1.

Table 6-1 Frequency of initiating events

PARAMETER	VALUE	SOURCE
Short circuit within a circuit breaker	0.0022 per I_s Limiter site per annum	Based on a failure rate for all circuit breaker faults from NAFIRS[7], adjusted using values from the IEEE Gold Book for the proportion of failures that are short circuits and allowing for 10 circuit breakers on average per site.
Short circuit of the feeder cables	0.322 per I_s Limiter site per annum	Based on a failure rate from NAFIRS data for Electricity North West per 100km of cable and assuming (based on fault current estimates) that an excessive fault current could only arise due to a short circuit in the first 700m of cable and that on average there are 10 feeder cables per substation. It is assumed that all short circuits will develop from phase to earth to phase to phase before feeder CB operates.
Short circuit of the overhead line	0.4284 per I_s Limiter site per annum	Based on a failure rate from NAFIRS data for Electricity North West per 100km of overhead line and assuming (based on fault current estimates) that an excessive fault current could only arise due to a short circuit in the first 700m of overhead line and that on average there are 6 feeders per substation. It is assumed that all short circuits will develop from phase to earth to phase to phase before feeder CB operates.

6.3.2 Probability of I_s Limiter Failure

The I_s Limiter has been the subject of an assessment by TUV Rhineland (Report on the determination of the safety related reliability of the I_s Limiter type BA 323/04 E January 2007 report Number 968/EL 444.00/07). This gave failure rates for the 3 phase I_s Limiter itself as in Table 1 below.

Table 6-2 I_s Limiter failure input data

PARAMETER	VALUE	SOURCE
Fail Dangerous Detected	147 FIT (failures per 10^9 hours)	TUV Rhineland Report
Fail Dangerous Undetected	24 FIT (failures per 10^9 hours)	TUV Rhineland Report
I_s power supply	100 FIT (failures per 10^9 hours)	Based on estimate of 500,000 hours for power supply but both main and back up need to fail (assumed common cause failure rate 5%)

These figures have been converted into a probability of failure on demand of 0.000109 which corresponds to SIL 3. Therefore, the I_s Limiter application would need to meet the requirements of SIL 3.

6.3.3 Probability of Worker Fatality

The probability of a worker fatality in the event of an explosion due to an initiating event has been estimated as 0.00001. This assumes that there is a procedure in place such that the network will

[7] National Fault and Interruption Reporting Scheme

be reconfigured to reduce fault level within equipment capabilities before a worker enters the substation. Given that these sites are unmanned the normal probability that a worker is in a substation has been estimated at 90 hours per year (i.e. 1% of the time) by the HAZID workshop team. Given the procedure of reconfiguration before a worker enters a site it is expected the probability of this procedure failing is 1 in 100. The probability that the worker is actually killed by the explosion resulting from the I_s Limiter failing has been estimated as 0.1. Together these assumptions lead to the overall probability of a worker being killed of 0.01*0.01*0.1 = 0.00001.

6.3.4 Probability of Public Fatality

The probability of a member of the public being killed in the event of an explosion event is dependent on the specifics of the site. For the purposes of this analysis it has been assumed there are high, medium and low risk sites.

A high-risk site has been defined as a site where the risk of public fatality is high (between 0.3 and 0.03 or 1 in 3 to 1 in 30). This means that people would need to be present a high percentage of the time and that an explosion due to the release of the fault energy would need to present a risk to these people either because the substation itself collapses and the people are close enough to be killed by the collapse or because of a feeder cable failing due to excess fault current is directly underneath a person and the ground or cable duct does not contain the release of the energy. The Event Tree analysis has assumed the geometric mean case (0.1) for high risk substations.

A medium risk site has been defined as a site where the risk of public fatality is medium (between 0.03 and 0.003 or 1 in 30 to 1 in 300). This means that people would need to be present a significant percentage of the time and that any explosion would need to present a risk to these people either because the substation itself collapses and the people are close enough to be killed by the collapse or because the feeder cable failing due to excess fault current is directly underneath a person and the ground or cable duct does not contain the release of energy. The Event Tree analysis has assumed the geometric mean case (0.01) for medium risk substations.

A low risk site has been defined where the risk of public fatality is low (less than 0.003 or 1 in 300). The Event tree analysis has assumed a value of 0.001 for low risk substations (geometric mean of 0003 to 0.0003).

An example of a high-risk site would be where there is a substation in a busy area (e.g. a shopping centre) and that site was not protected against explosions inside the substation or of the cable and the cable is not rated for the fault current that could occur if the I_s Limiter failed. It is suspected that sites in this type of situation are likely to incorporate measures to protect against explosions because there are already possible causes of such explosions on these sites but this must be allowed as a possibility.

An example of a medium risk site would be an urban site where the feeder cable runs under the pavement at a school entrance and could rupture due to excess fault current and the failure is not contained. If it is estimated that people gather outside school gates around 2 hours per day (1 in 10) and that these people occupy 35m out of the possible 700m failure zone for the feeder cable (1 in 20). This gives an overall risk of 1 in 200 which is within the medium risk boundaries.

Another example of a medium risk site would be an urban site where a house is situated in the substation building collapse zone and substation is not blast proof. It is estimated that the risk that the building collapses on the side where the house is situated is 1 in 4 and the risk that the building is occupied at the time is 1 in 2 and then that the person(s) in the house are killed is 1 in 5. This gives a total risk of 1 in 40 which is medium risk.

6.4 QRA RESULTS

The Event Trees are presented in Appendix A and summarised in the Table below which compares the overall risk with the targets for 'Tolerable' and also 'Broadly Acceptable'. They are also shown graphically in Figure 6-1. It should be noted that the low risk category includes feeder cable substations and those with overhead line feeders. These have slightly different risks. It has been assumed that no medium or high-risk sites have overhead line feeders because these are generally only used in rural situations.

Figure 6-1 Respond I_s Limiter Risks

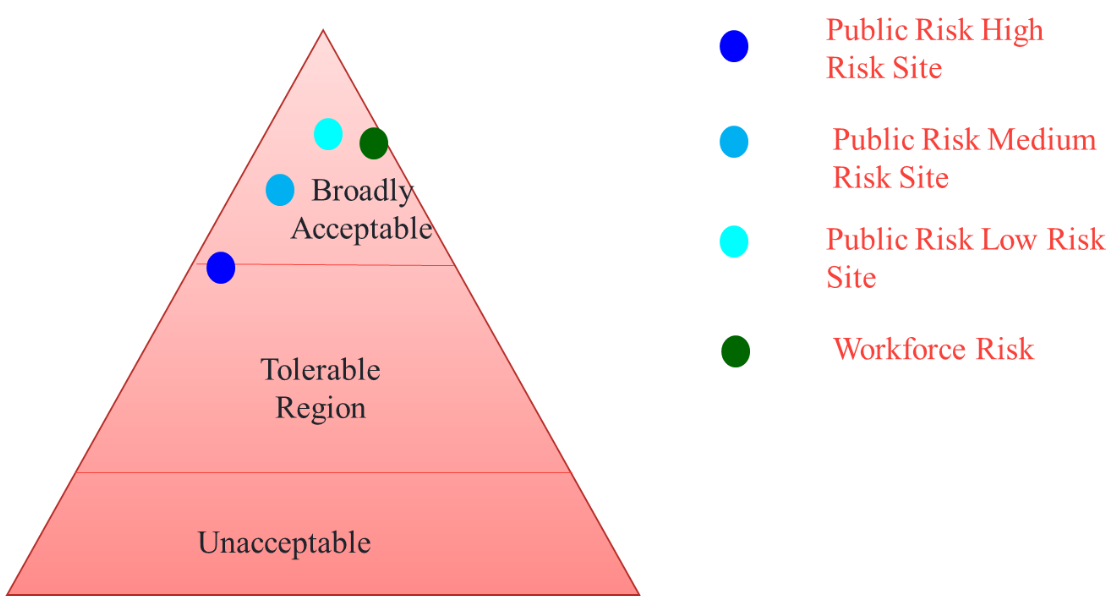

Table 6-3 QRA Results

Consequence	Frequency per site per annum	'Tolerable' upper limit per site per annum (all Respond hazards)	Meets 'Tolerable' upper limit?	'Broadly Acceptable' limit per site per annum	Meets 'Broadly Acceptable' limit?	Further risk reduction factor required for 'Broadly Acceptable'
Public fatality High Risk	$3.66\text{x}10^{-6}$	$3.54\text{ x}10^{-4}$	Yes	$3.54\text{ x}10^{-6}$	No	
Public fatality Medium Risk	$3.66\text{ x}10^{-7}$	$3.54\text{ x}10^{-4}$	Yes	$3.54\text{ x}10^{-6}$	Yes	
Public fatality Low Risk (Overhead Line)	$8.31\text{ x}10^{-8}$	$3.54\text{ x}10^{-4}$	Yes	$3.54\text{ x}10^{-6}$	Yes	
Public fatality Low Risk	$3.66\text{ x}10^{-8}$	$3.54\text{ x}10^{-4}$	Yes	$3.54\text{ x}10^{-6}$	Yes	

(Feeder Cable)						
Workforce Fatality	8.31 x10- 10	3.53 x10-5	Yes	3.53 x10-8	Yes	

6.5 DISCUSSION OF RESULTS

The QRA results indicate based on the adopted methodology and all assumptions, that the requirement that risks should be reduced to the “Broadly Acceptable” level as advised by HSE is met for all sites except for “High Risk” sites. For these sites the predicted figure is very close to the requirement so this means that sites with risk below the median level of “High Risk” would meet the requirement.

6.6 SENSITIVITY ANALYSIS

The analysis in this report is based upon a number of estimates and assumptions which might be subject to challenge and review. It is not possible to estimate whether the failure rates are conservative or not because they were estimated by a third party and the methodology is not known. It is estimated that the probability of a worker entering an I_s Limiter site without it being reconfigured beforehand so as to reduce fault currents (which is part of the agreed procedures) is 1 in 100. Given that the worker would clearly be putting themselves at risk and that the industry understands the importance of correct operation to protect people it is felt that this is a reasonably conservative assumption. It is assumed that if there is a network fault then a circuit breaker or cable carrying fault current above its rating will fail in an explosive manner whilst in reality it is quite possible that it may actually withstand the increased current. It is also assumed that all faults in feeder cables or OHL would develop from phase to earth to phase to phase before the feeder CB operates, which is a clearly conservative assumption.

It should be noted that the margin between the estimated frequency of fatality and the broadly acceptable level is a factor of ten in all cases except the “High Risk” case which gives a further level of confidence in the conclusions.

6.7 SAFETY REQUIREMENTS

The risk assessment has identified safeguards, controls and mitigation measures necessary to manage the level of risk associated with the implementation of the defined I_s Limiter scheme. These become the safety requirements which the I_s Limiter implementation must achieve to ensure control of the risk associated with each of the hazard scenarios and for the defined I_s Limiter scheme to present a ‘Tolerable’ level of safety risk. Referring to the complete list of safety requirements presented in Appendix C, these include:

a) Application conditions that must be satisfied before applying I_s Limiter to a site, i.e. pre-requisites

   SRs 7, 16, 20

b) Safety function and performance measures necessary for the I_s Limiter system, including safety integrity level

   SRs 1, 3, 9,10, 11, 12, 13, 14, 15, 17, 21

c) Risk reduction measures for high risk sites to reduce risk to medium risk.

   SR 4

d) Implementation, operating and maintenance measures necessary to control safety risk of the I_s Limiter scheme in use, including compliance with safety management systems, standards, procedures and codes of practice.

SRs 2, 5, 6, 8, 18, 19

6.8 NEXT STEPS

Tasks required to finalise this safety justification include:

- Electricity North West requests that another DNO conducts a formal review of this safety justification in order to increase stakeholder participation and strengthen the value of the report. Another DNO (UK Power Networks) has already been briefed on the approach, methodology and findings of this I_s Limiter safety justification and so may be a useful party to seek this further engagement from.

- Electricity North West conducts a formal review of this safety justification to confirm that objectives have been achieved and then use them as input to developing a plan for possible future implementation of an I_s Limiter scheme.

The potential for a wider future development and implementation of an I_s Limiter scheme is included in Section 7.2.

7 CONCLUSIONS

7.1 SUMMARY

This study has proposed a safety justification for implementation of the defined I_s Limiter scheme within the Electricity North West network.

The analysis has shown that, based on arguably conservative assumptions, that it would be acceptable from a safety viewpoint to install I_s Limiter systems in primary substations provided that they are not high risk sites or are high risk sites that have a risk lower than the median level.

Using recognised safety assessment processes, hazards associated with the I_s Limiter scheme have been identified. Means of eliminating, controlling or mitigating the potential consequences of these hazards have been established. A quantified risk assessment has been performed which demonstrates the residual safety risk presented to workers and to members of the public by the defined scheme.

Four hazard scenarios associated with the implementation of the defined I_s Limiter scheme have been determined to present the most significant risk. These include the potential for the failure of feeder cables and fire and/or structural damage at substations, possibly causing injuries and fatality for workers and members of the public.

Safety requirements (further to those already in place for the existing network and operations) have been established by the risk assessment based on the detailed input data and assumptions. Achievement of these safety requirements would ensure control of the risk associated with each of these scenarios and the defined I_s Limiter scheme would present a Tolerable safety risk. The safety requirements include:

a) Application conditions that must be satisfied before applying I_s Limiter to a site, i.e. pre-requisites

b) Safety function and performance measures necessary for the I_s Limiter system, including meeting safety integrity level 3

c) Implementation, operating and maintenance measures necessary to control safety risk of the I_s Limiter scheme in use, including compliance with safety management systems, standards, procedures and codes of practice.

The study has also reviewed the requirements laid down by health and safety applicable legislation relevant to the defined I_s Limiter scheme. This identified 'absolute' requirements of the EAW Regulations, specifically Regulations 5, 11 and 12 which, unlike other legislation requirements, are not satisfied by 'reasonably practicable' risk control measures and safety arguments. The EAW Regulations, Regulation 29, sets out the means for a legal defence in the event these 'absolute' regulations are breached.

This point has been discussed with HSE and a point of view offered by HSE was that provided a risk assessment had been performed which justified that the risk presented by the I_s Limiter scheme was 'Broadly Acceptable' then this would support an Electricity North West claim that it had taken sufficient steps to comply with the Regulations.

The study has therefore considered steps that could be taken by Electricity North West to demonstrate that risks associated with the defined I_s Limiter scheme are 'Broadly Acceptable' for all scenarios.

Further risk reduction measures would be required to protect the public at very high-risk sites, e.g. at a shopping centre.

By ensuring that substation structures and cable routes can contain the effects fault energy release at very high-risk sites so that the risk becomes lower than the median for such sites, the risk associated with the scenario would then become 'Broadly Acceptable'.

7.2 FURTHER DEVELOPMENT TO SUPPORT FUTURE IMPLEMENTATION

It is proposed that Electricity North West requests another DNO such as UK Power Networks to conduct a formal review of this safety justification in order to increase stakeholder participation and strengthen the value of the report. UK Power Networks has already been briefed on the approach, methodology and findings of this I_s Limiter safety justification and so may be a useful party to seek this further engagement from.

It is recommended that Electricity North West conducts a formal review of this safety justification to confirm that objectives have been achieved and to use as input to be developing a plan for possible future implementation of an I_s Limiter scheme and incremental safety justifications. The results of this will inform future steps in the development and application of the technique.

The scope of this study has been purposely constrained to the consideration of safety associated with implementing the defined I_s Limiter scheme. It is recommended that additional investigation and analysis of a possible I_s Limiter scheme is performed by Electricity North West in areas such as the business and operational risk, cost, legal implications and business strategy to contribute further to the business case.

Subject to these additional steps, it is recommended that Electricity North West takes forward the development of the I_s Limiter scheme with appropriate level of validation of achievement of the required SIL for the solutions adopted.

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APPENDIX A
HAZARD LIST

ID	HAZARD	CONSEQUENCE
1	Transformer high current caused by short circuit fault in the downstream system, i.e. on a feeder circuit.	Fault current within equipment rating. Upstream Tx CB provides protection within operating envelope.
2	Increased fault current flowing through the transformer causes increased oil degradation.	Inconsequential. Operation within rating and for a short time, causing insignificant change to the existing (non-I_S-Limiter) situation with regards oil degradation and ageing.
3	High current in transformer CB due to short circuit fault of the transformer.	Fault current within equipment rating. For Tx primary CB, operation of upstream protection causing removal of HV feed to single primary. For Tx secondary CB, operation of Tx primary CB causing removal of Tx secondary feed to busbar.
4	Increased fault current flowing through the transformer CB may cause additional degradation.	Operation within rating and for a short time, causing insignificant change to the existing situation with regards oil degradation and ageing.
5	Bus coupler high current caused by short circuit fault in the CB	Inconsequential. Operation within rating causing insignificant change to the existing situation.
6	Increased fault current flowing through the bus coupler CB may cause additional degradation.	Inconsequential. Operation within rating causing insignificant change to the existing situation.
7	Busbar A/B high current caused by short circuit fault at the busbar.	Public and workers potentially exposed to hazards. The busbar will see a peak current and thermal impact which will have to be tolerated. The peak asymmetrical fault current may be in excess of the busbar through fault current withstand rating. Busbar required to operate with excessive current. Excessive thermal conditions or excessive forces leading to explosion (civil - structural damage) resulting in potential fatality.
8	Short circuit fault. Fault level currents in excess of equipment ratings.	Public and workers potentially exposed to hazards. Explosion that could cause damage to structures and consequential potential fatality.
9	Lack of power supply to I_S Limiter due to interruption in distribution system.	Loss of protection - I_S Limiter loss of functionality during absence of power supply, with potential for failure of I_S Limiter to operate on demand. No impact from individual supply loss because of the duplication and monitoring of the power supplies.
10	Distribution voltage is higher than operational limits of I_S Limiter design (too high, surge, glitch).	Loss of protection - I_S Limiter control circuit could be damaged (detected or undetected), with potential for failure of I_S Limiter to operate on demand.
11	Distribution voltage is lower than operational limits of I_S Limiter design (too low, circuit fault, maintenance error)	Loss of protection - mal-operation of the I_S Limiter control circuit (detected or undetected), with potential for failure of I_S Limiter to operate on demand.
12	High current due to short circuit fault of the feeder CB	Network equipment could operate with excessive current. Excessive thermal conditions leading to fire resulting in potential fatality. The CB may not be able to interrupt the fault current. Public and workers potentially exposed to hazards due to explosion within the substation. Subsequent structural damage leading to hazards for nearby workers and public.

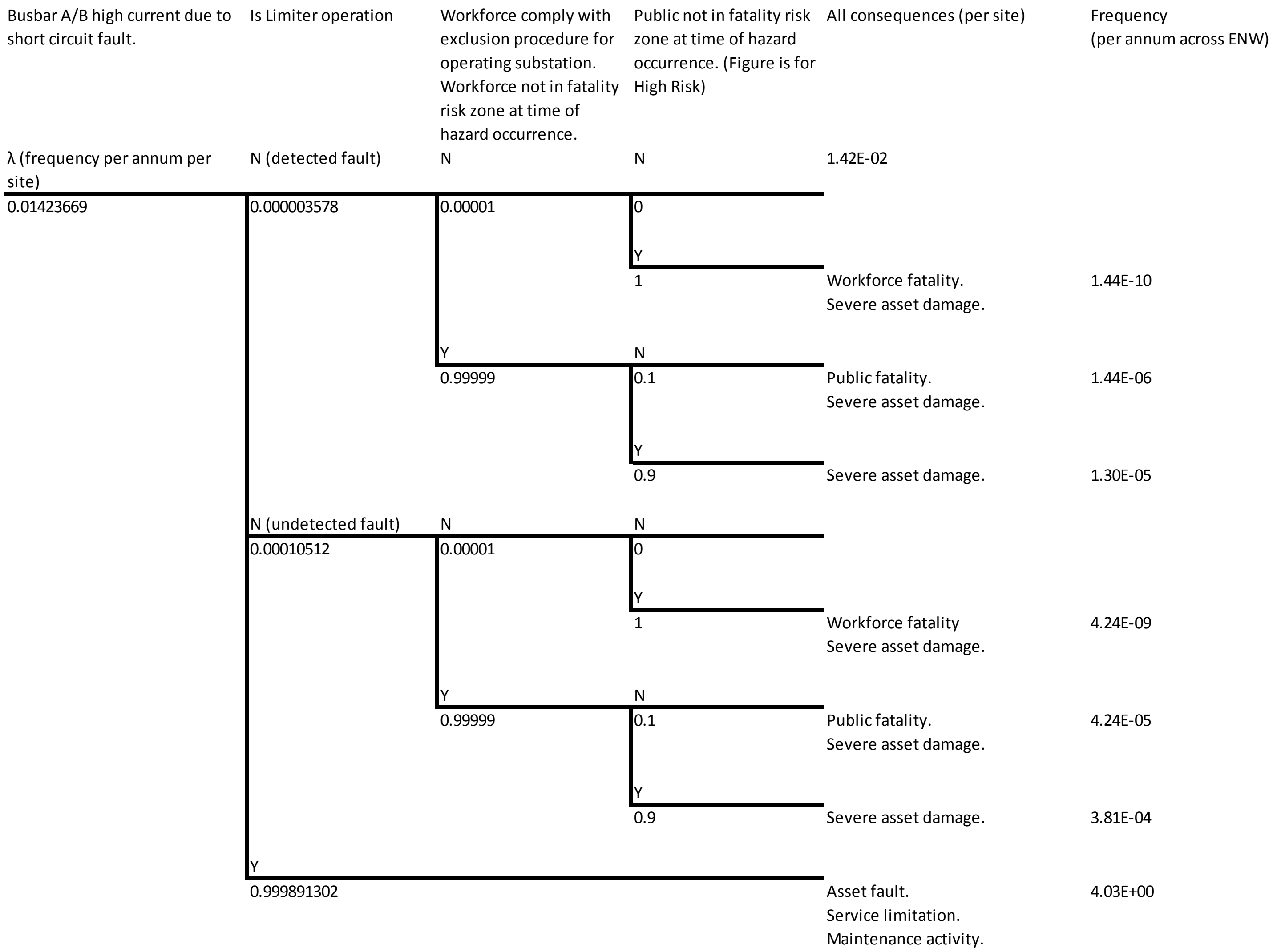
ID	HAZARD	CONSEQUENCE
13	Feeder CB fails to operate due to internal CB failure,the CB will not switch, but will experience through fault current. A consequence is that the fault currents are in excess of the CB through fault rating.	Public and workers potentially exposed to hazards. The CB will experience through fault current potentially in excess of the CB through fault rating, with potential for fire or fatality.
14	Failure of CTs connected to the feeder CB relay.	Public and workers potentially exposed to hazards. The relay will not send trip signals so the CB will not try to switch, but will experience through fault current potentially in excess of the CB through fault rating, with potential for fire or fatality.
15	Feeder CB operation at higher fault levels causes oil degradation and more contact wear.	Erosion is caused by the increased fault current flow. Degraded operation is more likely, as is failure on demand. (Refer to high current - deviation).
16	Feeder CB operation at higher fault levels causes oil degradation and more contact wear which requires more maintenance	Degraded operation is more likely, as is failure on demand. (Refer to high current - deviation).
17	I_s Limiter switch fails to operate on demand due to defect	Reduced protection if one phase will not operate, but other phases will still provide functional protection of the system. The I_s Limiter is rated to carry the prospective fault current. If two phases of the I_s Limiter switch simultaneously fail/defect then I_s Limiter functionality could be lost.
18	I_s Limiter switch damaged by lightning	Damage of the I_s Limiter (flashover). This could cause fire, which could lead to worker fatality. No significant change from existing risk.
19	High current by downstream fault not limited by operation of I_s Limiter	The I_s Limiter is rated to carry the prospective fault current. No additional risk introduced by the I_s Limiter.
20	I_s Limiter subjected to high temperature due to inadequate ventilation	Loss of protection - the charge element is deactivated/not able to operate. The I_s Limiter does not operate on demand with network consequences (refer to Feeder CB high current).
21	I_s Limiter subject to corrosion due to environmental or manufacturing impacts	Likely false tripping of the I_s Limiter (false tripping leads to operational inconvenience and cost). Very unlikely, impact could be failure to operate on demand (no credible mechanism identified).
22	Inadequate maintenance of I_s Limiter	At the extreme, the same as all the equipment, failure to operate on demand.
23	Damage to I_s Limiter upon insertion due to 1) Falling down/dropping and destroying the tripping wire connection. 2) Falling down/dropping and cracking the fuse.	At the extreme, the same as all the equipment, failure to operate on demand.
41	Failure of I_s Limiter to operate on demand due to incorrect or inappropriate settings	Limiter functionality lost hence reduced protection against overcurrent events
24	High temperature of I_s Limiter charge element due to local warming or failure of cooling fan	Loss of protection - the charge element is deactivated/not able to operate. The I_s Limiter does not operate on demand with network consequences (refer to Feeder CB high current).
25	Failure to operate on demand of I_s Limiter charge element due to defective manufacture or unexpected deterioration	One phase will not operate, but other phases will still provide functional protection of the system. The I_s-Limiter is rated to carry the prospective fault current.
26	Trip of I_s Limiter charge element without short circuit fault due to defective	Inconvenience but no safety consequences.

ID	HAZARD	CONSEQUENCE
	manufacture or unexpected deterioration	
27	Bypass CB fails short circuit when in parallel with in service I_s Limiter due to random failure or operator error leaving CB closed	Loss of protection - no limitation on short circuit current (because I_s Limiter is bypassed). In case of external fault, this CB will see fault current but within rating of CB.
28	I_s Limiter series circuit breaker failure to operate on demand	Reduced protection - fault current still interrupted by operation of I_s Limiter Switch in each phase.
29	I_s Limiter series circuit breaker no instrumentation, specifically no tripping signal from the I_s Limiter due to damage to the wire, damage to electronics initiating the signal	Reduced protection - CB does not operate. For a three-phase fault there is no issue because the three phases are open from the I_s Limiter. For a two-phase fault, only two phases are open circuited, while the third phase supply remains in unbalanced system conditions. No safety related consequences.
30	I_s Limiter series circuit breaker closes on fault due to failure of interlocking between I_s Limiter switch and CB.	All consequences relate to open circuit situations or unbalanced operation. Neither of which are dangerous.
31	Blocking doesn't block when should be blocking due to defect in internal control or external inputs.	Operates when shouldn't operate which is an inconvenience, but no safety consequences
32	Blocking blocks when should not be blocking due to defect in internal control or external inputs including damage to wiring.	Loss of protection - I_s Limiter does not operate when required and the fault current is unconstrained leading to network issues. In case of external fault, equipment between the fault side of the busbar and the fault location may see excessive fault current.
33	Self-monitoring indicates an issue when there isn't an issue due to electronics defect	Operator will reconfigure network and send out the maintenance team which is an inconvenience but not unsafe.
34	Self-monitoring does not indicate an issue when there is an issue due to electronics defect	Possible loss of protection - Control room will not be aware if there is a failure in the supervised part of the I_s Limiter electronics. I_s Limiter could not operate when it is expected to operate leading to network issues if the self-monitoring and I_s Limiter fail at the same time. CB operates with excessive fault current.
35	Fault indication does not get through to the control room or is ignored by the control room due to comms defect or controller error	Possible loss of protection - Control room will not be aware if there is a failure in the supervised part of the I_s Limiter electronics. I_s Limiter could not operate when it is expected to operate leading to network issues if the self-monitoring and I_s Limiter fail at the same time. CB operates with excessive fault current.
36	Lack of CT's inputs due to damage to CT or associated wiring from workforce, rodent	Loss of protection - Damaged phase will not operate, but other phases will still provide functional protection of the system if they are not damaged. If two or more phases are affected simultaneously eg by vermin, the I_s Limiter would/could fail to operate on demand. In case of external fault, equipment between the fault side of the busbar and the fault location may see excessive fault current.
37	Short circuit fault on feeder cables	Public and workers potentially exposed to hazards. Cable required to operate with excessive current. CB if operates correctly, will operate within 400ms. However, within this time the cables may be damaged. This might cause a fault cleared by normal means. Public and workers are potentially subject to danger. Cable joints are subject to excessive current and could cause a fault or explode with potential hazards to the public or workers. Potentially involving interruption of adjacent utilities.
38	Short circuit fault in customer premises causing high current in their switchgear	Public and workers potentially exposed. The switchgear will see a peak current, a thermal overload which it will have to tolerate. Switchgear required to operate with excessive current. Excessive thermal conditions leading

ID	HAZARD	CONSEQUENCE
		to fire resulting in potential fatality. The switchgear may not be able to interrupt the fault current
39	Short circuit fault in distribution network causing high current in distribution switchgear	Public and workers are subject to potential fatalities. The switchgear may experience an excessive fault current and may cause heating and potential fire. The breaker experiencing excessive fault current may have destructive failure.
40	Short circuit in overhead line	Public and workers are subject to danger. Increased fault level current could cause thermal rating exceedance (I^2t). OHL required to operate with excessive current. CB if operates correctly, will operate within 400ms. However, within this time the OHL may be damaged causing permanent deformation resulting in exceedance of clearance limits. This might cause a fault cleared by normal means.

APPENDIX B
EVENT TREES

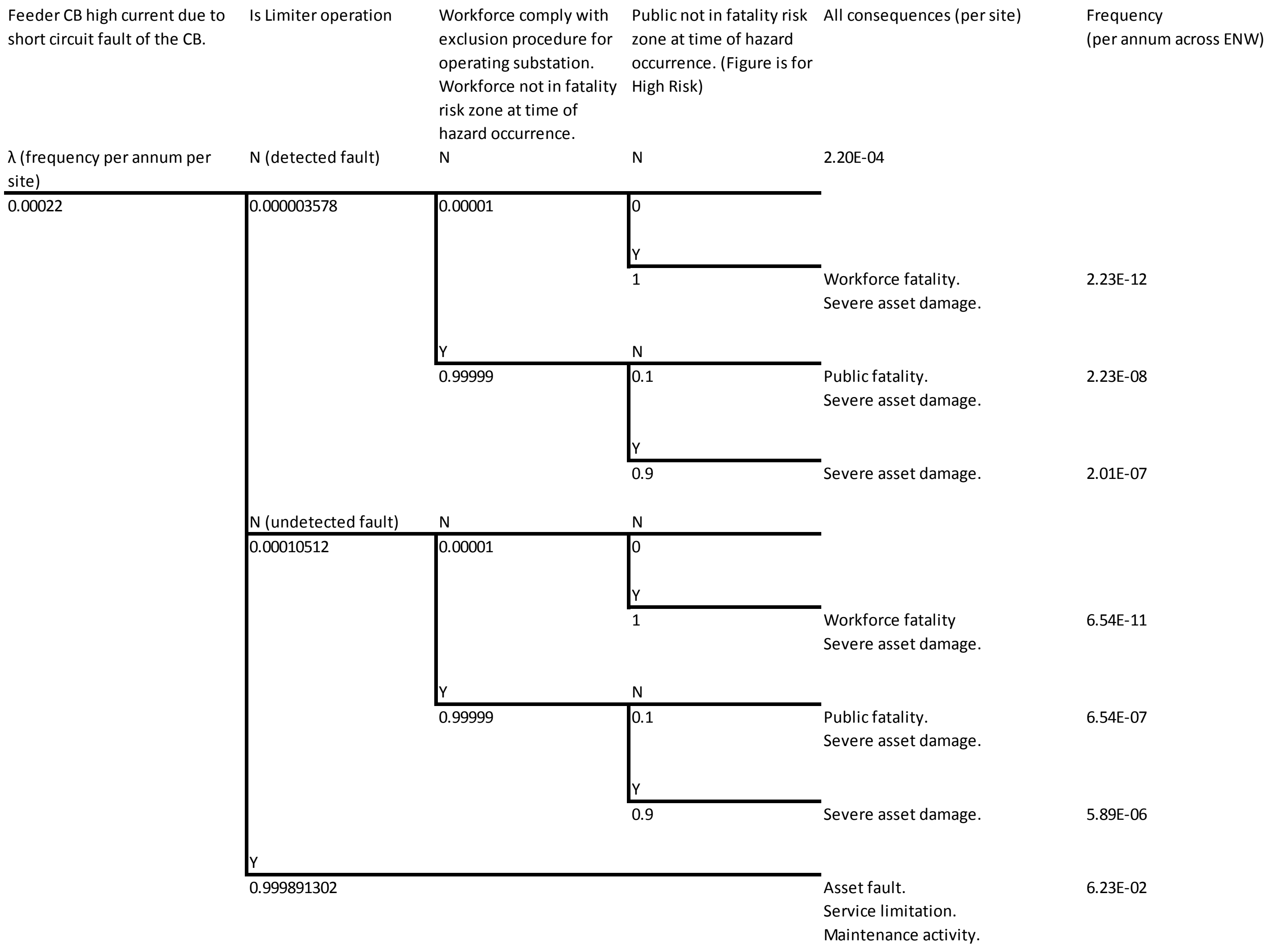
Short circuit of the busbar in a substation resulting in excessive fault current



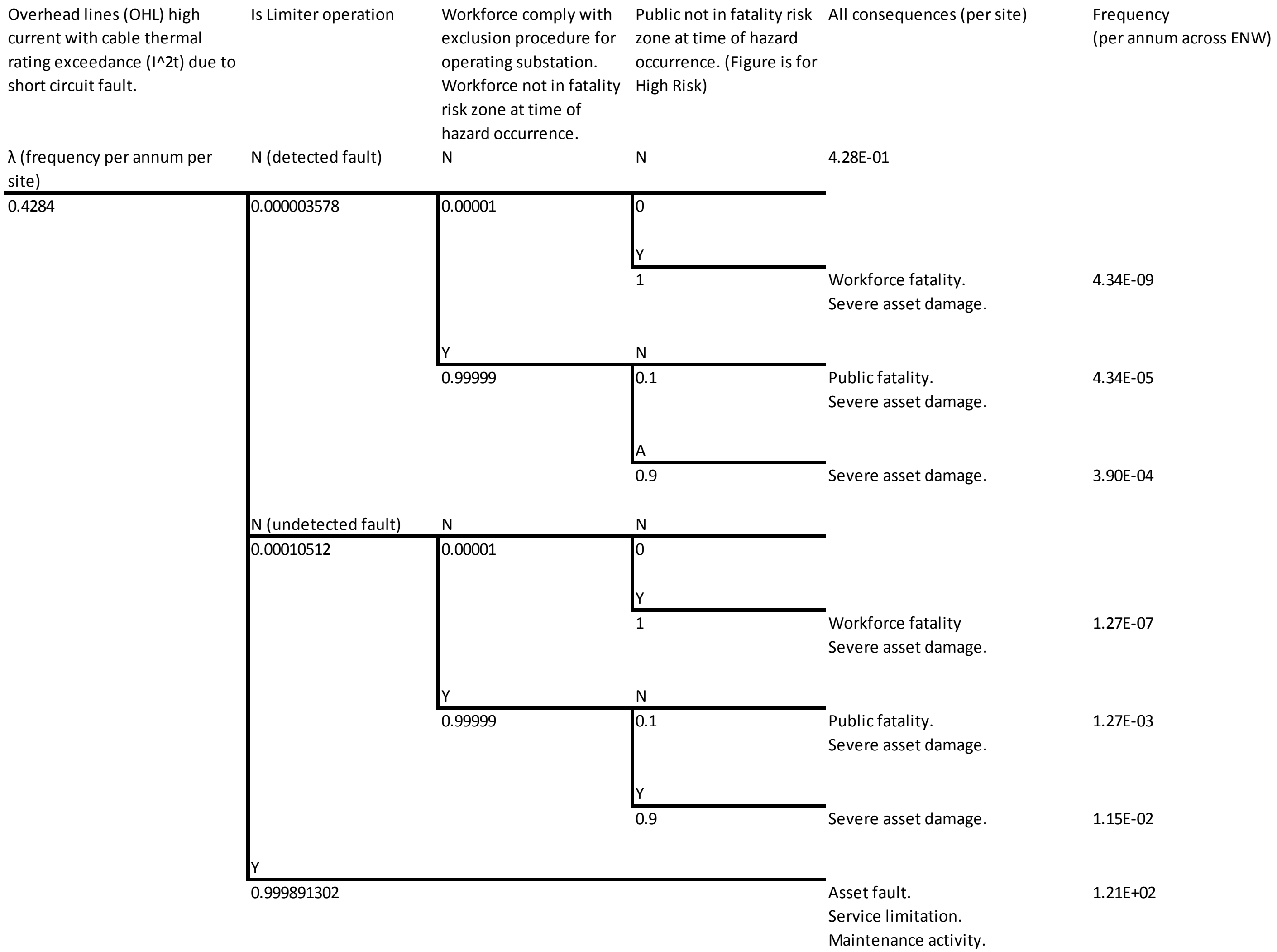
Short circuit of the feeder cables or something connected to these cables such that the feeder cable withstand current is exceeded

Feeder cables high current with cable thermal rating exceedance (I^2t) due to short circuit fault.	Is Limiter operation	Workforce comply with exclusion procedure for operating substation. Workforce not in fatality risk zone at time of hazard occurrence.	Public not in fatality risk zone at time of hazard occurrence. (Figure is for High Risk)	All consequences (per site)	Frequency (per annum across ENW)
λ (frequency per annum per site)	N (detected fault)	N	N	3.22E-01	
0.322	0.000003578	0.00001	0		
			Y 1	Workforce fatality. Severe asset damage.	3.26E-09
		Y 0.99999	N 0.1	Public fatality. Severe asset damage.	3.26E-05
			Y 0.9	Severe asset damage.	2.93E-04
	N (undetected fault) 0.00010512	N 0.00001	N 0		
			Y 1	Workforce fatality Severe asset damage.	9.58E-08
		Y 0.99999	N 0.1	Public fatality. Severe asset damage.	9.58E-04
			Y 0.9	Severe asset damage.	8.62E-03
	Y 0.999891302			Asset fault. Service limitation. Maintenance activity.	9.11E+01

Short circuit within a Circuit Breaker in the substation resulting in excessive fault current



Short circuit of the Overhead Line or something connected to the Overhead Line such that the Overhead Line withstand current is exceeded



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APPENDIX C
SAFETY REQUIREMENTS

ID.	RELATED HAZARDS	DESCRIPTION
SR1	7, 12,13, 14, 15, 16, 37, 40	Apply I_s Limiter
SR2	7, 12,13, 14, 15, 16, 37, 40	Before workforce enter substation, ensure operational procedures are followed to reduce prospective fault current to within limits (open busbar CB)
SR3	7, 12,13, 14, 15, 16, 37, 40	I_s Limiter would need to meet requirements of SIL 3
SR4	7, 12,13, 14, 15, 16, 37, 40	Substation structure explosion withstand capability; blast wall, additional containment, pressure relief (For high risk sites)
SR5	13, 14, 15, 16	Maintenance of CBs, Txs and busbars should appropriately reflect the frequency of operation
SR6	25	Storage, handling and installation procedures for I_s Limiter to be followed
SR7	9,10,11,17	I_s only to be installed where there is an alarm/warning system in the Control Room to indicate an I_s problem
SR8	9,10,11,17	Control engineer manually issues a signal to open the bus section to mitigate the fault level issue, in response to I_s fault alarm
SR9	10	The power supply to the I_s Limiter should incorporate overvoltage protection
SR10	11	The power supply to the I_s Limiter should incorporate undervoltage protection
SR11	41	Planning to specify appropriate settings for Limiter which are reviewed when any connections are added to the network to ensure that the switchgear is adequately rated, reviewed when the fault level changes, reviewed if the network is reconfigured or altered in a way that would change the prospective fault current at any location within the network
SR12	41	Satisfactory commissioning of I_s Limiter
SR13	41	Original Limiter settings to be such that they give maximum flexibility for predicted changes to fault currents

ID.	RELATED HAZARDS	DESCRIPTION
SR14	27	If bypass is fitted then Interlocking of Bypass CB and e.g. Bus Coupler CB to prevent network configuration with potentially excessive fault levels while Bypass CB closed / short circuit.
SR15	28	Full range fuses to be used wherever available
SR16	38	I_s Limiter only to be installed where the prospective fault current is within the rating of existing customer switchgear on any feeder or the fault level at a customers' site is equal to or less than the design fault level even if the I_s Limiter fails to operate
SR17	39	The Is limiter should be designed such that the fault current is kept within the rating of existing distribution switchgear on all feeder circuits providing the Is limiter correctly operates
SR18	20	Operations to monitor substation temperatures and take measures if they exceed permitted I_s Limiter temperatures
SR19	13,14,15,16,17,34	Periodic proof testing of I_s Limiter system and equipment to confirm all components functioning as intended and free of faults.
SR20	1,2,3,4	Transformer fault currents are within the rating of the transformer and its circuit breaker even if the I_s Limiter fails
SR21	32	Blocking circuitry needs to be designed with an appropriate level of fail safety

APPENDIX D
KEY REQUIREMENTS OF HEALTH & SAFETY APPLICABLE LEGISLATION

Note: The table below is not a complete definition of requirements from legislation applying to the design, implementation of an I_s Limiter scheme. It presents extracts from some relevant legislation and supplemental guidance – refer to original Acts, Regulations and associated supplemental guidance publications for a full description of requirements.

LEGISLATION AND GUIDANCE	REFERENCE	DESCRIPTION
HSW Act	Part 1, Section 2 (1)	General duties of employers to their employees: It shall be the duty of every employer to ensure, so far as is reasonably practicable, the health, safety and welfare at work of all his employees.
	Part 1, Section 2 (2)	General duties of employers to their employees: (a) the provision and maintenance of plant and systems of work that are, so far as is reasonably practicable, safe and without risks to health; (b) arrangements for ensuring, so far as is reasonably practicable, safety and absence of risks to health in connection with the use, handling, storage and transport of articles and substances; (c) the provision of such information, instruction, training and supervision as is necessary to ensure, so far as is reasonably practicable, the health and safety at work of his employees; (d) so far as is reasonably practicable as regards any place of work under the employer’s control, the maintenance of it in a condition that is safe and without risks to health and the provision and maintenance of means of access to and egress from it that are safe and without such risks; (e) the provision and maintenance of a working environment for his employees that is, so far as is reasonably practicable, safe, without risks to health, and adequate as regards facilities and arrangements for their welfare at work.
	Part 1, Section 3 (1)	General duties of employers and self-employed to persons other than their employees: It shall be the duty of every employer to conduct his undertaking in such a way as to ensure, so far as is reasonably practicable, that persons not in his employment who may be affected thereby are not thereby exposed to risks to their health or safety.
	Part 1, Section 6 (1)	General duties of manufacturers etc. as regards articles and substances for use at work. It shall be the duty of any person who designs, manufactures, imports or supplies any article for use at work- (a) to ensure, so far as is reasonably practicable, that the article is so designed and constructed that it will be safe and without risks to health at all times when it is being set, used, cleaned or maintained by a person at work; (b) to carry out or arrange for the carrying out of such testing and examination as may be necessary for the performance of the duty imposed on him by the preceding paragraph.

LEGISLATION AND GUIDANCE	REFERENCE	DESCRIPTION
	Part 1, Section 6 (2)	It shall be the duty of any person who undertakes the design or manufacture of any article for use at work to carry out or arrange for the carrying out of any necessary research with a view to the discovery and, so far as is reasonably practicable, the elimination or minimisation of any risks to health or safety to which the design or article may give rise.
Management of HSW Regulations	Regulation 3, (1)	Risk assessment: Every employer shall make a suitable and sufficient assessment of: a) The risks to the health and safety of his employees to which they are exposed whilst they are at work; and b) The risks to the health and safety of persons not in his employment arising out of or in connection with the conduct by him of his undertaking.
EAW Regulations	Regulation 4, (1)	All systems shall at all times be of such construction as to prevent, so far as is reasonably practicable, danger.
	Regulation 5	No electrical equipment shall be put into use where its strength and capability may be exceeded in such a way as may give rise to danger.
	Regulation 6	Electrical equipment which may reasonably foreseeably be exposed to: (a) mechanical damage; (b) the effects of the weather, natural hazards, temperature or pressure; (c) the effects of wet, dirty, dusty or corrosive conditions; or (d) any flammable or explosive substance, including dusts, vapours or gases, shall be of such construction or as necessary protected as to prevent, so far as is reasonably practicable, danger arising from such exposure.
	Regulation 11	Efficient means, suitably located, shall be provided for protecting from excess of current every part of a system as may be necessary to prevent danger.
	Regulation 12, (1)	Where necessary to prevent danger, suitable means (including, where appropriate, methods of identifying circuits) shall be available for–: (a) cutting off the supply of electrical energy to any electrical equipment; and (b) the isolation of any electrical equipment.
	Regulation 29	In any proceedings for an offence consisting of a contravention of regulations 4(4), 5, 8, 9, 10, 11, 12, 13, 14, 15, 16 or 25, it shall be a defence for any person to prove that he took all reasonable steps and exercised all due diligence to avoid the commission of that offence.
HSR25 2015	*Absolute/ Reasonably Practicable*	...
	...Clause 57	Duties in some of the Regulations are subject to the qualifying term 'reasonably practicable'. Where qualifying terms are absent the requirement in the regulation is said to be absolute. The meaning of reasonably practicable has been well established in law. The interpretations in paragraphs 59–60 are given only as a guide to dutyholders.
	...Clause 58	If the requirement in a regulation is 'absolute', for example if the requirement is not qualified by the words 'so far as is reasonably practicable', the requirement must be met regardless of cost or any other consideration. Regulations making such absolute requirements are subject to the defence provision of regulation 29.
	Regulation 5	...
	...Clause 80	The defence (regulation 29) is available in any proceedings for an offence under this regulation.

LEGISLATION AND GUIDANCE	REFERENCE	DESCRIPTION
	Clause 81	Before equipment is energised, the characteristics of the system to which the equipment is connected must be taken into account. This should include those existing under normal conditions, possible transient conditions and prospective fault conditions, so that the equipment is not subjected to stress which it is not capable of handling without giving rise to danger. The effects to be considered include voltage stress and the heating and electromagnetic effects of current.
	Clause 82	The term 'strength and capability' of electrical equipment refers to the ability of the equipment to withstand the thermal, electromagnetic, electrochemical or other effects of the electrical currents which might be expected to flow when the equipment is part of a system. These currents include, for example, load currents, transient overloads, fault currents, pulses of current and, for alternating current circuits, currents at various power factors and frequencies. Insulation must be effective to enable the equipment to withstand the applied voltage and any likely transient over-voltages.
	Clause 83	A knowledge of the electrical specification and the tests, usually based on the requirements of national or international standards, will assist the user in identifying the withstand properties of the equipment so that it may be selected and installed to comply with this regulation. Such tests are normally carried out either by the manufacturer or by an accredited testing organisation.
	Clause 84	The strength and capability of electrical equipment is not necessarily the same as its rating. Usually the rating is that which has been assigned by the manufacturer following a number of agreed tests.
	Clause 85	Electrical equipment should be used within the manufacturer's rating (continuous, intermittent or fault rating as appropriate) and in accordance with any instructions supplied with the equipment.
	Clause 86	So that equipment remains safe under prospective fault conditions, you must select equipment that takes account of the fault levels and the characteristics of the electrical protection which has been provided for the purpose of interrupting or reducing fault current (excess current protection is required by regulation 11). Most electrical equipment will be able to withstand short-circuit currents safely for limited periods only. The considerations also extend to conductors and equipment provided solely for protective purposes, eg earthing conductors must be adequately rated to survive beyond fault clearance times to ensure satisfactory protective gear operation and fault clearance.
	Regulation 11	...
	...Clause 167	The defence (regulation 29) is available in any proceedings for an offence under this regulation (see paragraphs 177–179).
	Clause 168	It is recognised that faults and overloads may occur on electrical systems. The regulation requires that systems and parts of systems be protected against the effects of short circuits and overloads if these would result in currents which would otherwise result in danger.
	Clause 169	The means of protection is likely to be in the form of fuses or circuit breakers controlled by relays etc, or it may be provided by some other means capable of interrupting the current or reducing it to a safe value.
	Clause 172	When selecting the means of protection, you must consider a number of factors – the more important of these include: (a) the nature of the circuits and type of equipment to be protected; (b) the short-circuit energy available in the supply (the fault level); (c) the nature of the environment; (d) whether the system is earthed or not.

LEGISLATION AND GUIDANCE	REFERENCE	DESCRIPTION
	Clause 173	The circuits to be dealt with may vary from high-power, high-voltage circuits, eg for the inter-connection of substations or for the supply to large motors, down to the smallest final circuit supplying a few low-power lamps at, say, 6 V. Over this range lies a great diversity of equipment, each item of which will possess characteristics which must be carefully considered in the selection of appropriate devices to protect against excess current.
	Clause 174	The maximum short-circuit current in the protected circuit must be considered. (The ability of circuit breakers and fuses to operate successfully and without dangerous effects, serious arcing or, in the case of oil-filled equipment, the liberation of oil, is implicit in the requirements of regulations 4 and 5.) The design of the protective arrangement must also provide for sufficient current to be available to operate the protective devices correctly in respect of all likely faults.
	Clause 177	The defence (regulation 29) is available in any proceedings for an offence under this regulation.
	Clause 178	In some circumstances it will be technically impossible to achieve total compliance with the absolute requirement to prevent danger. If an excess of current is drawn due to a fault or overload, eg due to an arcing fault, then whatever form of electrical protection is provided, there will be some danger at the point of the fault during the finite time taken for the detection and interruption of the fault current. Nevertheless, electrical protection – whether by means of a simple fuse or another method – must be properly chosen and installed in accordance with good electrical engineering practice. The protection must be efficient and effective.
	Regulation 12	...
	...Clause 185	The need for means to cut off the supply and effect isolation depends on factors such as likely danger in normal and abnormal conditions. This assessment may be influenced by environmental conditions and provisions to be made in case of emergencies, such as a fire in premises. It includes consideration of which electrical equipment could be a source of danger if such means were not provided and of the installation, commissioning, operational and maintenance requirements over the life of the equipment.
	Regulation 29	...
	...Clause 244	Regulation 29 applies only in criminal proceedings. It provides a defence for a dutyholder who can establish that they took all reasonable steps and exercised all due diligence to avoid committing an offence under regulations 4(4), 5, 8, 9, 10, 11, 12, 13, 14, 15 or 16.
HSG85 2013	Clause 8	Equipment must be properly designed, constructed, installed and maintained so that it does not present a risk of electric shock, burns, fire or explosion when properly used.
	Clause 12	You must select equipment that is suitable for the environment in which it is used, for example cables and equipment in heavy industries such as sheet metal works need to be protected against mechanical damage. You should consider adverse environmental factors when working on equipment. For example, excessively damp or humid conditions will increase the risk of injury because of reduced effectiveness of insulation, which may undermine the effectiveness of devices used for isolation, or increase the severity should an electric shock occur. Equipment that has corroded may not function as intended.

LEGISLATION AND GUIDANCE	REFERENCE	DESCRIPTION
ESQC Regulations	Regulation 3, (1)	Generators, distributors and meter operators shall ensure that their equipment is: (a) sufficient for the purposes for and the circumstances in which it is used; and (b) so constructed, installed, protected (both electrically and mechanically), used and maintained as to prevent danger, interference with or interruption of supply, so far as is reasonably practicable.
	Regulation 4	Generators, distributors, suppliers and meter operators shall: (a) disclose such information to each other as might reasonably be required in order to ensure compliance with these Regulations; and (b) otherwise co-operate amongst themselves so far as is necessary in order to ensure compliance with these Regulations.
	Regulation 6	A generator or distributor shall be responsible for the application of such protective devices to his network as will, so far as is reasonably practicable, prevent any current, including any leakage to earth, from flowing in any part of his network for such a period that that part of his network can no longer carry that current without danger.
	Regulation 23, (1)	A distributor shall ensure that his network shall be: (a) so arranged; and (b) so provided, where necessary, with fuses or automatic switching devices, appropriately located and set, as to restrict, so far as is reasonably practicable, the number of consumers affected by any fault in his network.
	Regulation 24, (1)	A distributor or meter operator shall ensure that each item of his equipment which is on a consumer's premises but which is not under the control of the consumer (whether forming part of the consumer's installation or not) is: (a) suitable for its purpose; (b) installed and, so far as is reasonably practicable, maintained so as to prevent danger; and (c) protected by a suitable fusible cut-out or circuit breaker which is situated as close as is reasonably practicable to the supply terminals.
	Regulation 28	A distributor shall provide, in respect of any existing or proposed consumer's installation which is connected or is to be connected to his network, to any person who can show a reasonable cause for requiring the information, a written statement of— (a) the maximum prospective short circuit current at the supply terminals; (b) for low voltage connections, the maximum earth loop impedance of the earth fault path outside the installation; (c) the type and rating of the distributor's protective device or devices nearest to the supply terminals; (d) the type of earthing system applicable to the connection; and (e) the information specified in regulation 27(1), which apply, or will apply, to that installation.