Part of Energy Queensland

Network Standard

Standard for Arc Flash

These standards created and made available are for the construction of Energy Queensland infrastructure. These standards ensure meeting of Energy Queensland's requirements. External companies should not use these standards to construct non-Energy Queensland assets.

If this standard is a printed version, to ensure compliance, reference must be made to the Energy Queensland internet site www.energyq.com.au to obtain the latest version.

Approver	Carmelo Noel General Manager Asset Standards	
If RPEQ Sign-off required insert details below.		
Certified Person Name and Position Title	Registration Number	
John Lansley Manager Substation Standards		

Abstract: The purpose of this standard is to ensure that plant purchases and business systems minimise the incident energy workers may be exposed to from arc flash hazards. This document outlines the design specifications and engineering practices required for analysing, mitigating, and documenting arc flash hazards on electrical equipment owned and acquired by Energy Queensland. It defines the accepted practices for considering arc flash hazards during equipment assessments and designing to reduce arc flash hazard for both high voltage (HV) and low voltage (LV) installations.

Keywords: arc blast, arc fault currents, arc flash, arc-flash boundary, arc-flash hazard, arc-flash hazard analysis, electrical hazard, IEEE 1584™, incident energy, personal protective equipment, PPE, working distance

CONTENTS

FIGURES

TABLES

1 Overview

1.1 Purpose

The purpose of the standard is to ensure personnel are not exposed to energy from a potential arcing fault that presents an unacceptable safety risk. The DNSP shall ensure network assets owned, installed, and are operated in a manner that manages exposure to incident energy resulting from an arc flash.

1.2 Scope

This document sets out specification, design and engineering practices which must be followed in respect of the analysis, mitigation, and documentation of arc flash hazards on electrical equipment owned, proposed, or to be installed by the DNSP.

This standard defines the recommended steps to consider regarding arc flash hazards during equipment assessments and design to minimise this hazard. It is intended to ensure that consistent arc flash hazard analysis and mitigation outcomes are achieved across Energy Queensland's operations.

The standard applies to both new and existing installations and shall be applied for any augmentation that affects the arc flash incident energy levels that personnel may be exposed to. Although arc-flash is not a new phenomenon, its treatment within electrical safety practice has evolved significantly. The underlying physics and potential consequences of an arcing fault have always existed; however, advances in engineering knowledge, modelling tools and contemporary risk-management principles now allow these consequences to be more accurately understood, quantified and mitigated. This standard reflects that progression by ensuring that Energy Queensland consistently applies current best-practice methods for identifying, analysing and managing arc-flash hazards across both new and existing installations. In doing so, it supports the broader obligation under Queensland's electrical safety framework to eliminate or minimise electrical risk—of which arc-flash is one element—so far as is reasonably practicable.

Examples of augmentations that may affect incident energy exposure include:

- New switchboard installations
- Changes to protection performance
- Supply transformer upgrades
- Switchboard modification e.g. but not limited to the following.
    - Medium Voltage circuit breaker truck replacement
    - Low voltage air circuit breaker replacement
- Use of alternative power supplies like permanent generator or renewable energy installations

The scope of this standard includes, but is not limited to the following items:

- Medium Voltage Switchboards/RMUs
- Low Voltage Switchboards
- Low Voltage Distribution Boards

Currently excluded from scope:

- Priority of asset assessment

- How to perform an arc flash study
- Substation primary plant connected to outdoor busbar i.e. Outdoor circuit breakers Ur ≥ 3.3kV
- Overhead conductors (bare and LVABC)
- Uninterruptable Power Supplies (UPS)
- Grid connected Energy storage systems such as BESS, refer to AS/NZS 5139:2019
- Work practices and work instructions for live work are excluded from the scope of this standard

The output from an arc flash hazard analysis is not a risk assessment. It is considered as the consequence of an event that includes arc flash energy, light, sound, and pressure. This consequence will need further consideration via business risk management process.

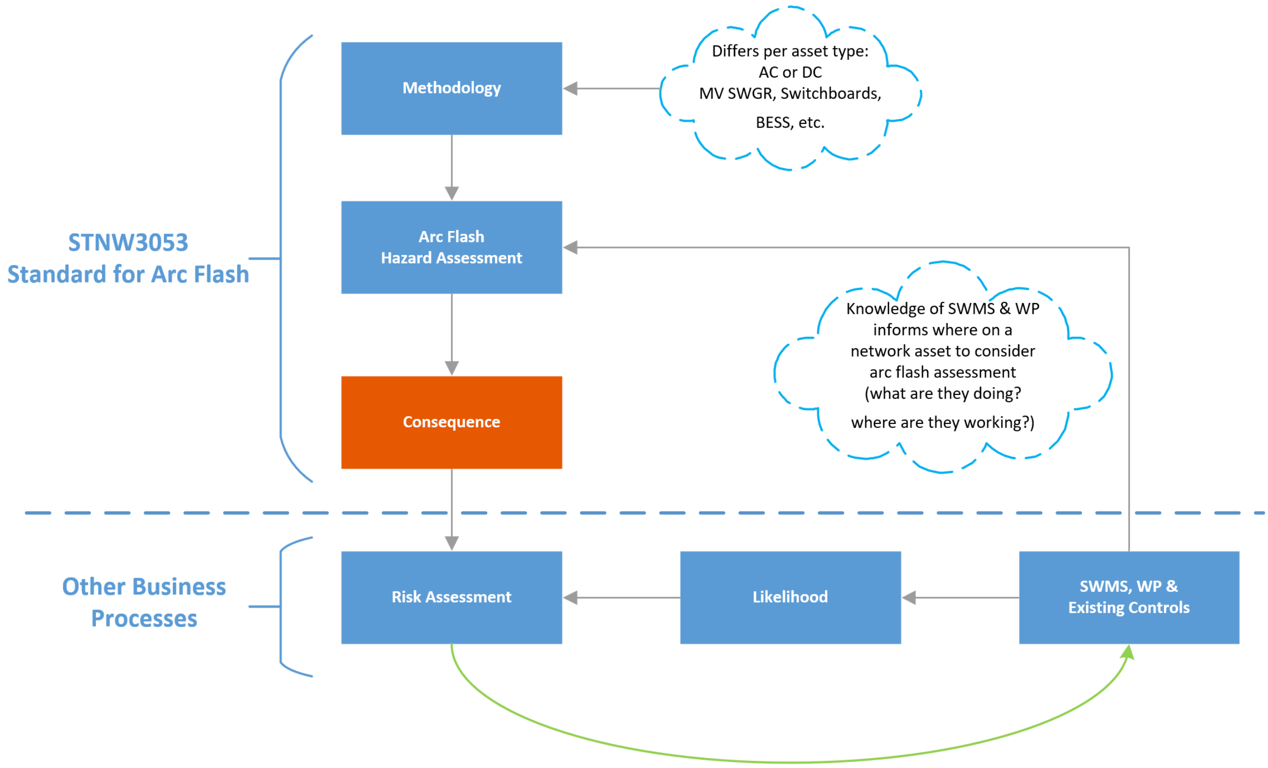

Figure 1: Assessment Process

2 References

2.1 Legislation, Regulations, Rules, and Codes

Document	Type
Electricity Act 1994 (Qld)	Legislation
Electricity Regulation 2006 (Qld)	Regulation
Electrical Safety Act 2002 (Qld)	Legislation
Electrical Safety Code of Practice – Works, 2020 (Queensland Government)	Code
Electrical Safety Regulation 2013 (Qld)	Regulation
Fire Services Act 1990 (Qld)	Legislation
Queensland Electricity Act, 1994	Legislation
Queensland Electrical Safety Regulation, 2013 (Qld)	Regulation
Queensland Work Health and Safety Act, 2011(Qld)	Legislation
Queensland Work Health and Safety Regulation, 2011 (Qld)	Regulation

2.2 Controlled Documents

Document	Alternative Doc ID
Arc Flash Risk Management Framework - 24760246	
Electrical Safety Rules - 6503074	
Enterprise Risk Management Standard R271 - 689958	R271
Job Safety and Environmental Analysis Framework - 690212	R267
Risk Evaluation Matrix R056 - 691861	R056
Risk Management Procedure - 9937852	
Standard for Classifying the Condition of Network Assets - 2948464	STNW0330 (EE) 00707 (EX)
Standard for Clearances in Air - 3054141	STNW3013
Standard for Maintenance Acceptance Criteria - 2928929	STNW1160
Standard for Personal Protective Equipment (PPE) S031 - 691352	S031
Standard for Substation AC Supplies - 39259289	STNW3023
Standard for Substation Design Requirements - 20468486	STNW3003
Standard for Substation Signage - 2941554	STNW3037
Standard for Switchgear Selection - 12743722	STNW3051

2.3 Other Sources

AS/NZS 3000:2018	Electrical installations (known as the Australian/New Zealand Wiring Rules).
AS/NZS 3008.1.1:2017	Electrical Installations - Selection of Cables Part 1.1: Cables for alternating voltages up to and including 0.6/1 kV - Typical Australian installation conditions
AS/NZS 4836:2023	Safe working on or near low-voltage and extra-low voltage electrical installations and equipment.
AS/NZS 5139:2019	Electrical installations - Safety of battery systems for use with power conversion equipment
AS/NZS 61439.1:2026	Low-voltage switchgear and controlgear assemblies Part 1: General rules
AS/NZS 61439.2:2026	Low-voltage switchgear and controlgear assemblies Part 2: Power switchgear and controlgear assemblies
AS/NZS 61439.3:2016	Low-voltage switchgear and controlgear assemblies Part 3: Distribution boards intended to be operated by ordinary persons (DBO)
AS 62271.1:2019	High-voltage switchgear and controlgear, Part 1 Common specifications for alternating current switchgear and controlgear (IEC 62271-1:2017, MOD)
AS 62271.100:2019	High-voltage switchgear and controlgear, Part 100 Alternating-current circuit-breakers (IEC 62271-100:2008+AMD1:2012+AMD2:2017 CSV (ED. 2.2)/COR1:2018, MOD)
AS 62271.200:2019	High-voltage switchgear and controlgear, Part 200 AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV (IEC 62271-200:2011/COR1:2015, MOD)
ENA NENS 09 – 2014	National Guideline for the Selection, Use and Maintenance of Personal Protective Equipment for Electrical Arc Hazards
IEEE 1584:2018	Guide for performing arc-flash hazard calculations
IEEE 1584.1:2022	Guide for the Specification of Scope and Deliverable Requirements for an Arc-Flash Hazard Calculation Study in Accordance with IEEE Std 1584
IEEE 1584.2	Draft Guide and Checklists for the Data Collection for Performing an Arc-Flash Hazard Calculation Study in Accordance with IEEE Std 1584 and IEEE Std 1584.1 for Systems Operating at Three-Phase 50/60 Hz Alternating Current (AC) 1000 V and Below
NFPA 70E:2024	Standard for Electrical Safety in the Workplace

IEEE Paper	Arc-Flash Hazard Calculation Study in Accordance with IEEE Std 1584 and IEEE Std 1584.1 for Systems Operating at Three-Phase 50/60 Hz Alternating Current (AC) 1000 V and Below
IEEE Paper PCIC-2021-54	A Practical Application of IEEE STD 1584-2018
IEEE Paper	Arc Flash Hazards of 125 Vdc Station Battery Systems

3 Definitions and Abbreviations

3.1 Definitions

For the purposes of this standard, the following definitions apply.

2 second rule	If the total protective device clearing time is longer than two seconds (2 s); consideration shall be given to how long a person is likely to remain in the location of the arc flash. It is likely that a person exposed to an arc flash will move away quickly if it is physically possible, and 2 s usually is a reasonable assumption for the arc duration to determine the incident energy (IEEE 1584, 2018).
Alteration	A modification to part(s) of an electrical installation. NOTE: Repairs are not alterations. (AS/NZS 3000, 2018)
Arc Flash	The uncontrolled release of energy (arc plasma) due to an electrical arcing fault through air (phase to phase or phase to earth).
Arc Fault Current	Fault current flowing in air, through an electrical arc plasma.
Arc Flash Hazard	The danger of excessive heat exposure and serious burn injuries due to the arc plasma that is ejected at high speeds due to the associated pressure wave.
Arc Flash Equipment Category	A fixed combination of items that when combined, produce a given Arc Flash outcome. The Arc Flash outcome may vary depending upon where in the EQL network the plant is installed.
Assembly System	Full range of mechanical and electrical components (enclosures, busbars, functional units, etc.), as defined by the original manufacturer, which can be assembled in accordance with the original manufacturer's instructions to produce various Assemblies.
Arc Duration	Refers to the time of an arcing event on the primary system. See arcing time.
Arcing Time	The time interval between initial separation of the primary current-carrying contacts of a switching device and final extinction of the power-frequency arc within the circuit breaker. Arcing time varies depending upon circuit breaker voltage, type, and interruption medium.

Arc thermal performance value	A measurement of a material's ability to protect a person from a burn due to exposure to incident energy resulting from an arc flash explosion. Measured in calories per centimetre squared.
Barrier	A part providing basic protection from any usual direction of access (AS/NZS 3000, 2018)
Busbar	A strip or bar of copper, brass or aluminium conducting electricity within a switchboard, distribution board, substation, or other electrical apparatus.
Category 1 PPE	Personal Protective Equipment with a ATPV of up to 4 cal/cm², (16.72 J/cm²).
Category 2 PPE	Personal Protective Equipment with a ATPV of up to 8 cal/cm², (33.47 J/cm²)
Category 3 PPE	Personal Protective Equipment with a ATPV of up to 25 cal/cm², (104.6 J/cm²).
Category 4 PPE	Personal Protective Equipment with a ATPV of up to 40 cal/cm², (167.36 J/cm²).
Circuit breaker mechanical opening time	The time interval between energisation of the circuit breaker trip device (e.g. trip coil) and initial separation of the primary current-carrying contacts.
Clearing Time	The time interval between inception of fault current and final arc extinction on the primary system. Clearing time may be achieved by operation of a local switching device, a remote switching device, or a sequence of coordinated operations. Accordingly, clearing time may comprise: • Clearing Time (Local), • Clearing Time (Remote), or • A combination of sequential local and remote clearing actions, including delays associated with intertrip transmission. The effective clearing time for a given fault condition is the total elapsed time until fault current interruption is achieved.
Clearing Time (Local)	The time interval between inception of fault current and final arc extinction at the primary contacts of the local switching device. This is the sum of: Protection Operating Time • Interposing Relay Operating Time (where installed) • Local Circuit Breaker Mechanical Opening Time • Local Circuit Breaker Arcing Time
Clearing Time (Remote)	The time interval between inception of fault current and final arc extinction at the primary contacts of the remote switching device. This is the sum of:

	• Protection Operating Time (sending end) • Intertrip Transmission Time • Interposing Relay Operating Time (where installed) • Remote Circuit Breaker Mechanical Opening Time • Remote Circuit Breaker Arcing Time
Conductor Gap	Used in (IEEE 1584, 2018) to define the spacing between busbars or conductors at the arc location.
Contact, direct	Contact with a conductor or conductive part that is live in normal service. Basic protection is required (AS/NZS 3000, 2018).
Contact, indirect	Contact with a conductive part that is not normally live but has become live under fault conditions (because of insulation failure or some other cause). Fault protection is required (AS/NZS 3000, 2018).
Distribution board	Low voltage electrical distribution switchboard.
DNSP	Distribution Network Service Provider. Depending on the context DNSP means either Energex (who owns and operates the distribution system in Southeast Queensland) or Ergon Energy Network (who owns and operates the distribution system in the remainder of Queensland)
Electrode Configuration	The orientation and arrangement of the electrodes used in the testing performed for the model development. The following electrode configurations (test arrangements) are defined within the incident energy model: • VCB: Vertical conductors/electrodes inside a metal box/enclosure • VCBB: Vertical conductors/electrodes terminated in an insulating barrier inside a metal box/enclosure. • HCB: Horizontal conductors/electrodes inside a metal box/enclosure • VOA: Vertical conductors/electrodes in open air • HOA: Horizontal conductors/electrodes in open air
Electrode Gap	Same as Conductor Gap
Exposed	Bare; or not effectively insulated; or not effectively guarded by either a fixed barrier or an earthed metal shield. (Electricial Safety Act, 2002)
Exposed Part	An exposed conductor or an exposed component of an item of electrical equipment. (Electricial Safety Act, 2002)
Extra-low voltage	A voltage not exceeding 50 V AC or 120 V ripple-free DC (AS/NZS 3000, 2018)

Ground Mount Transformer	A ground mounted distribution transformer, typically with a HV cable box and LV cable box or shrouded terminals
Hazard Risk Category	A rating factor used by (NFPA70E, 2024) to nominate the incident energy that may exist within the specified working distance due to an arcing fault.
High voltage	Voltages that exceed low voltage (AS/NZS 3000, 2018).
Incident Energy	The amount of thermal energy impressed on a surface, a certain distance from the source, generated during an electric arc event. NOTE 1—The incident energy is calculated at the working distance. Incident energy increases as the distance from the potential arc source decreases, and the incident energy decreases as the distance increases. NOTE 2—The units used to measure incident energy are Joules per square centimetre (J/cm^2) or calories per square centimetre (cal/cm^2).
Internal arc classified switchgear and controlgear (IAC)	Metal-enclosed switchgear and controlgear for which prescribed criteria, for protection of persons, are met in the event of internal arc as demonstrated by type tests (AS 62271 Part 200, 2019).
Interposing relay operating time	The time interval between energisation of the interposing relay input circuit by a control or protection signal and the operation of its output contacts.
Intertrip Transmission Time	The time interval between the generation of a remote trip command at the sending end terminal and the energisation of the circuit breaker trip device at the remote terminal, including all signalling equipment processing, communications channel propagation, and receiving-end control circuit delays.
Low voltage	Voltages that exceed extra-low voltage but do not exceed 1000 V AC or 1500 V DC (AS/NZS 3000, 2018).
Low-Voltage Switchgear And Controlgear Assembly – shortened - Assembly	Combination of one or more low-voltage switching devices together with associated control, measuring, signalling, protective, regulating equipment, with all the internal electrical and mechanical interconnections and structural parts.
Metal-Enclosed Switchgear And Controlgear	Switchgear and controlgear assemblies with an external metal enclosure intended to be earthed and completely assembled, except for external connections (Medium Voltage) (AS 62271 Part 200, 2019).
Obstacle	A part preventing unintentional direct contact, but not preventing direct contact by deliberate action (AS/NZS 3000).
On or Near	Within 3m of exposed energised conductors or live conductive parts.

	Note 1 to entry: The term "on or near exposed energized conductors or live conductive parts" does not apply if the uninsulated and energized part is safely and securely shielded by design or segregated and protected with barricades or insulated shrouding or insulating material to prevent inadvertent or direct contact. Note 2 to entry: The term "on or near" includes an activity which may affect the properties of conductors or conductive parts and cause them to be exposed energized conductors or live conductive parts. (AS/NZS 4836, 2023).
Padmount Transformer Or Kiosk Transformer	A ground mounted distribution transformer, typically packaged with a HV ring main unit and low voltage switchboard
Protection operating time	The time interval between the inception of a fault and the issue of a trip command by the protection system to the associated switching device. Protection operating time includes sensing, measurement, decision-making, and output contact or signal delays within the protection scheme.
Prospective Short-Circuit Current I_{cp}	r.m.s. value of the current which would flow if the supply conductors to the circuit are short circuited by a conductor of negligible impedance located as near as practicable to the supply terminals of the assembly. (AS/NZS 61439.1, 2016)
Protected extra-low voltage	An extra-low voltage system that is not electrically separated from earth, but that otherwise satisfies all the requirements for SELV (AS/NZS 3000, 2018).
Protection, Basic	Protection against dangers that may arise from direct contact with live parts of the installation (AS/NZS 3000, 2018).
Protection, Fault	Protection against dangers that may arise from indirect contact with live parts of the installation (AS/NZS 3000, 2018).
PSC-Assembly	Power switchgear and controlgear assembly. Low-voltage switchgear and controlgear assembly used to distribute and control energy for all types of loads, intended for industrial, commercial and similar applications where operation by ordinary persons is not intended. (AS/NZS 61439.2, 2016)
Repair	The work to restore the electrical installation to safe and sound working condition after deterioration* or damage* has occurred. (AS/NZS 3000, 2018). *Any other reason would need to be treated as an Alteration.
Separated extra-low voltage	An extra-low voltage system that is electrically separated from earth and from other systems in such a way that a single fault cannot give rise to the risk of electric shock (AS/NZS 3000, 2018).
Short-Circuit	A fault having a metallic conducting path between any two or more conductors or between any conductor and ground, including touching conductors and faults through earthing facilities.

Should	Means an expected outcome unless it can be demonstrated and is documented that it is inappropriate for a particular circumstance. These departures need to be approved by the Substation Standards Manager.
Switchgear and controlgear	General term covering switching devices and their combination with associated control, measuring, protective and regulating equipment, also assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures
Type of Accessibility	Characteristic related to the level of protection given to people accessing a defined area around the enclosure of switchgear and controlgear. (AS 62271 Part 200, 2019).
Working Distance	The distance between the potential arc source and the face and chest of the worker performing the task. (IEEE 1584, 2018)
Work On	Performance of a function within 500 mm of exposed energized conductors or live conductive parts and/or electrical equipment. (AS/NZS 4836, 2023).
Work Near	Performance of a function within 3 m of exposed energized conductors or live conductive parts and/or electrical equipment. (AS/NZS 4836, 2023).

3.2 Abbreviations

This list does not include well-known unambiguous abbreviations, or abbreviations defined at their first occurrence within the text.

AC or a.c.	Alternating Current
ATPV	Arc Thermal Performance Value
BESS	Battery Energy Storage System
DBO	Distribution boards intended to be operated by ordinary persons
DC or d.c.	Direct Current
HV	High Voltage (>1000 V a.c. or >1500 V d.c.)
HRC	High Rupture Capacity
IED	Intelligent Electronic Device
ELV	Extra Low Voltage (<50 V a.c. or <120 V d.c.)
IAC	Internal arc classified switchgear and controlgear
IP	Ingress Protection
ISO	International Organisation for Standardization
LV	Low Voltage (≤ 1000 V a.c. or ≤ 1500 V d.c.)
MAC	Maintenance Acceptance Criteria

NATA	Australian National Association of Testing Authorities
NZS	New Zealand Standard
PVC	Polyvinyl chloride
QA	Quality Assurance
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition
SI	International System
IEEE	Institute of Electrical and Electronics Engineers (American Standards)
NFPA	The National Fire Protection Association (American Standards)

4 Background

An arc flash is the uncontrolled release of energy (arc plasma) due to an electrical arcing fault through air (phase to phase or phase to earth). These faults produce intense heat, sound blasts and pressure waves, which can vaporize metal and initiate combustion in nearby materials, presenting risks of fire or explosion. Arc flash can result in significant harm, such as severe burns, hearing impairment, vision loss, respiratory damage, and in certain instances, and lead to fatalities.

An arc flash hazard is the danger of exposure to excessive heat, and serious burn injuries due to the arc plasma that is ejected at high speeds and the associated pressure wave.

Once it starts, an arc flash can quickly escalate into a plasma cloud. The extremely high temperatures at the origin of the arc breaks down air molecules forming a conductive path. Through this path, the fault current flows, unleashing a substantial amount of energy. The arc plasma itself is a superheated, ionized, conductive, magnetic gas which creates a severe burning hazard. The result is an explosion of light, heat, hot gases, and molten metal, reaching temperatures of up to 20,000ºC.

Besides the potential human risk of injury or fatality due to an arc flash, other impacts may include consequential damage because of the explosion, such as structural failure in switchboards and projection of molten metal, detached panels/doors, equipment parts, along with other debris.

The arc flash level is determined by the incident energy. The incident energy is defined as the amount of thermal energy impressed on a surface, a specific distance away from the source during an electrical arc event. Incident Energy is measured in Joules per centimeter squared (J/cm^2) or in calories per centimeter squared (cal/cm^2) and determines the arc flash hazard category level of switchgear, required PPE and boundary distance.

Some possible causes of an arc flash are:

- Momentary shorting due to, for example, a dropped tool or bolt, or accidental contact with live parts.
- Ionisation of air due to over-heating (hot-spots) or transient over-voltage (e.g. lightning).
- Solid insulation deterioration due to partial discharge or ageing.
- Pollution by water, dust, or foreign matter.
- Corrosion.
- Conductive dust particles.
- Misalignment of moving contacts.
- Entry of foreign bodies (e.g. insects, rodents, snakes).

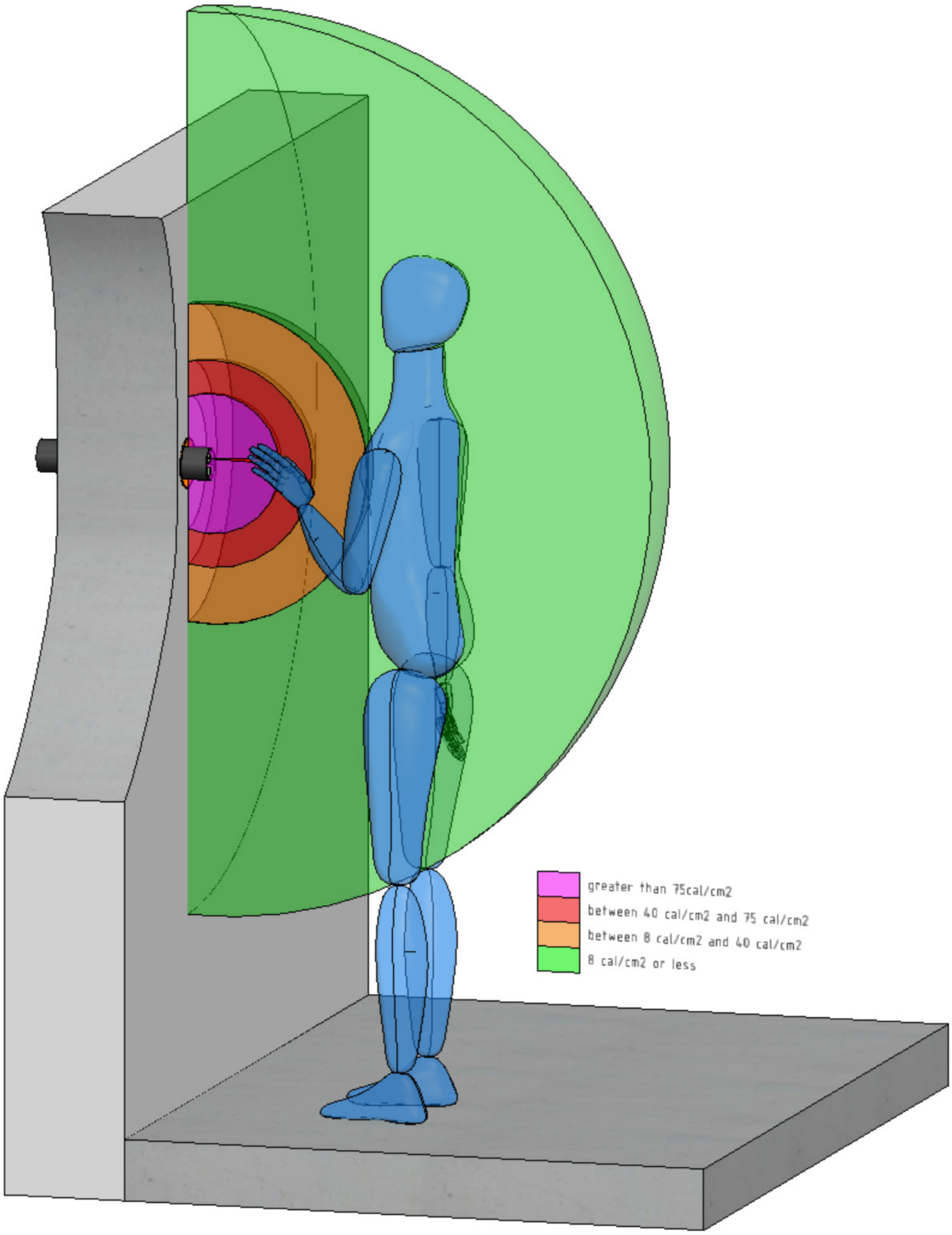

Figure 2: Worker Exposed to Arc Flash Event

Figure 2 Shows a worker exposed to an arc flash event. The concentric spheres represent the boundaries for different levels of incident energy illustrating the importance of understanding task and worker distance from the source of the arc flash.

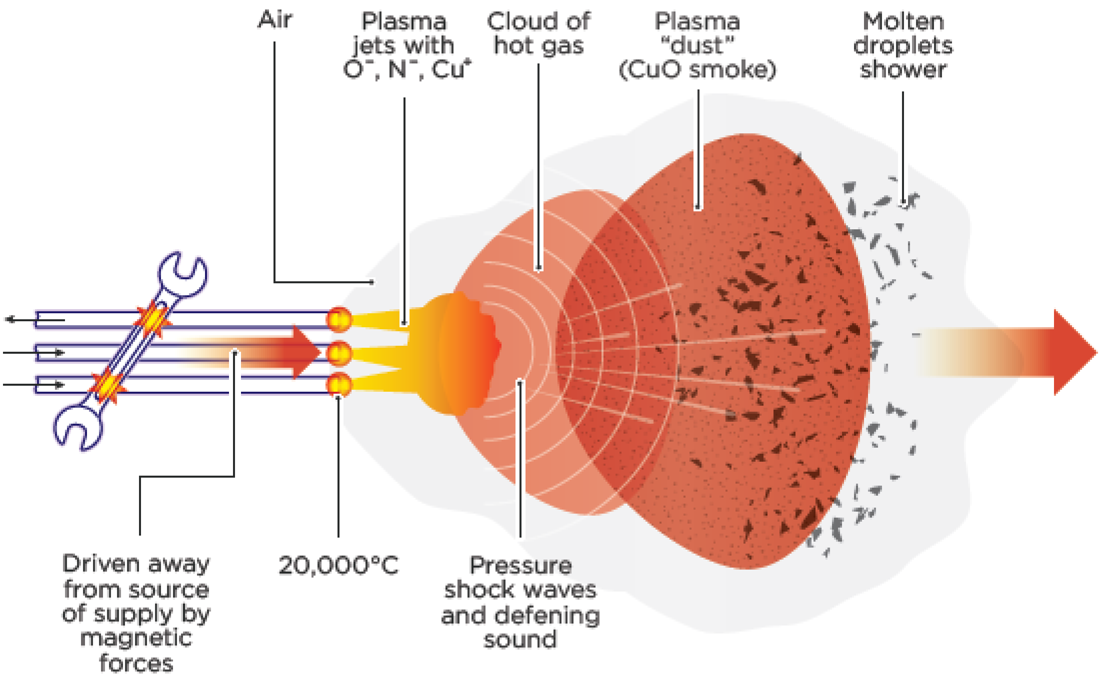

Figure 3: What is an Arc Flash?[1]

[1] Diagram 7, What is an Arc Flash, Energy Council of Australia. (2019). Electrical Arc Flash Hazard Management Guideline - Energy Council of Australia.

5 Arc Flash Hazard Assessment

The outcome of an arc flash hazard assessment is a consequence, and it is not by itself, a risk assessment. The calculations that provide an arc flash hazard assessment do not include the likelihood of the event, nor any control measures that may be in place to mitigate the consequence. Analysis of consequence shall follow existing EQL (Risk Management Procedure - 9937852, 2023) and (Enterprise Risk Management Standard R271 689958, 2023).

5.1 General

An arc flash hazard assessment shall be undertaken for new works and for alterations to existing assets where the work may affect the incident energy that personnel could be exposed to.

Arc flash hazard assessments are required for the following types of work:

1. New installations, assessed during engineering feasibility and confirmed at design using:
   - standardised approaches for standard plant, or
   - bespoke assessment per Annex A for non-standard plant.
2. Alterations to existing medium voltage and low voltage assets where the change may:
   - material alteration of the available fault current;
   - change protection device type, settings, logic, or clearing time;
   - alter arc containment or arc mitigation capability; or
   - change how the installation operates in a way that could influence incident energy.
3. All existing medium voltage and low voltage assets.
4. Permanent changes to network configuration that introduce substantially different upstream source characteristics, such as connection to a mobile substation, supply transformer upgrades, or reconfiguration that materially strengthens or weakens the source.
5. Product procurement and development affecting assets covered by this standard.
6. Post-event investigations, where arc flash may have contributed to the event or its severity.

5.1.1 Alterations That Do Not Require an Arc Flash Hazard Assessment

Alterations that do not influence fault level, protection performance, fault clearing time, or arc containment (such as replacement of control wiring, door hardware, auxiliary devices, labels, or non-electrical components) do not require an arc flash assessment.

Repairs to existing electrical installations or parts thereof may be affected using methods, fixtures and fittings that were acceptable when that part of the electrical installation was originally installed or with methods, fixtures and fittings currently available as direct replacement.

5.1.2 Design Documentation Requirement

The designer shall record the basis for determining whether an arc flash assessment is required as part of the project documentation.

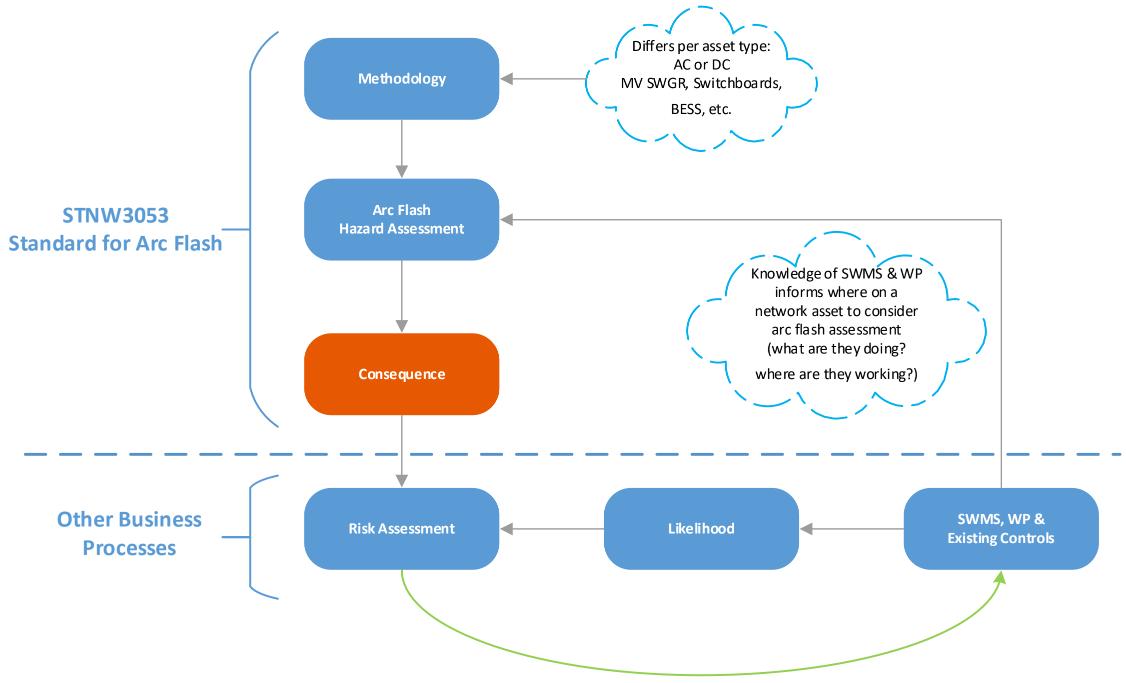

Figure 4: Arc Flash Hazard Assessment Process

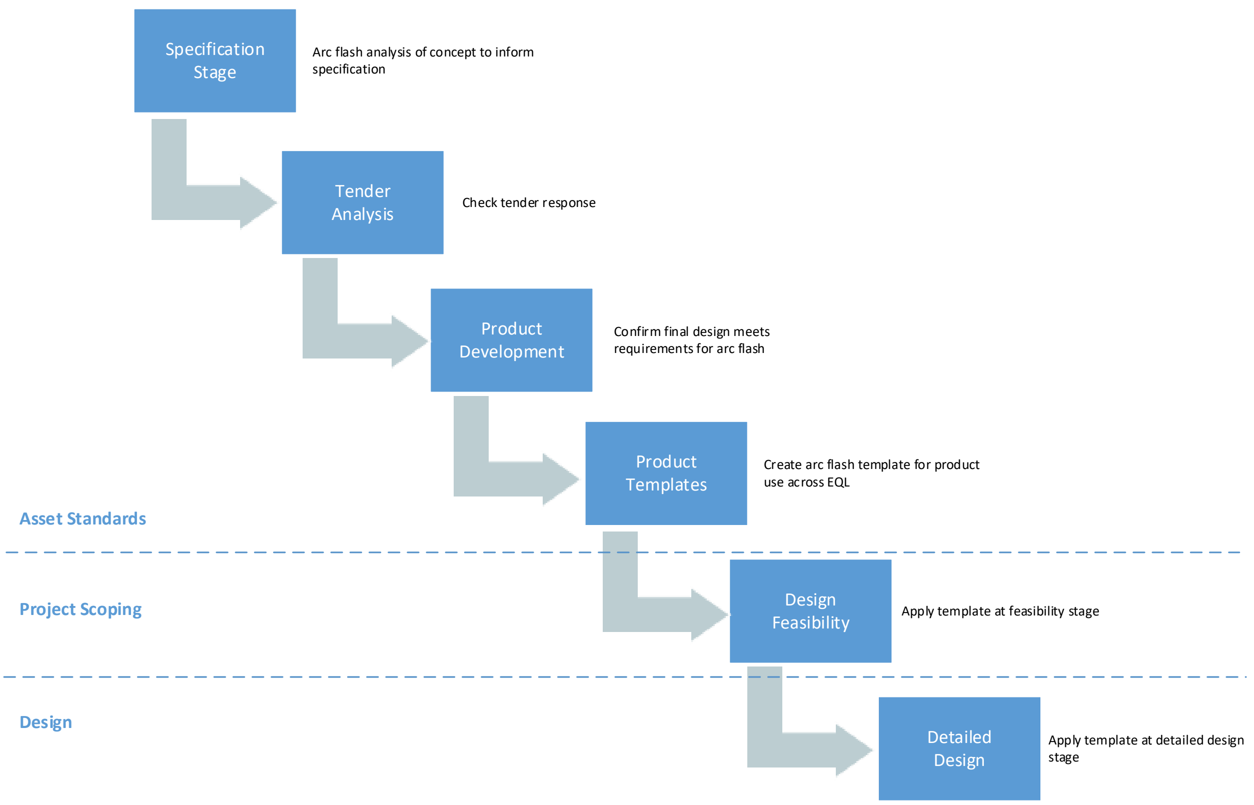

Figure 5: Product Development and Use

5.2 Energy Source Contributions to the Arc-Flash Model

The arc flash model must consider credible energy sources including but not limited to:

- Normal and abnormal supply sources.

- Normal and abnormal switching scenarios.
- Inverter connected systems such as Battery Energy Storage Systems (BESS) and Solar
- Diesel generator/s (permanent and/or mobile generators).
- Large motor contributions.

5.3 Where Incident Energy Calculations are Not Required

5.3.1 Operational Switching and Load Transfers

Routine HV operational switching, load transfers, and feeder reconfigurations do not require an arc flash hazard assessment unless the change results in a material alteration of the fault level or protection clearing time.

A material alteration is defined as a change that it introduces a substantially different HV source characteristic.

Normal operational transfers between feeders within a bulk or zone substation, or between bulk or zone substations of similar short-circuit capacity, are not considered material changes for the purposes of this standard.

Note: Reducing fault level by operational means (e.g. bus splitting) does not necessarily reduce arc-flash incident energy. Lower fault current may cause protection to operate outside its instantaneous region, increasing clearing time and potentially increasing incident energy.

5.3.2 Small LV Supplies

Incident energy calculation is not required where the equipment under consideration is supplied via a radial circuit at low voltage, and is protected by an upstream low voltage circuit breaker or fuse, with ratings of:

- 1Φ supply, 150 A or less,
- 3Φ supply, 63A or less

Refer (AS/NZS 4836, 2023) tables 11.2 and B1, and IEEE paper (Arc Flash Hazards of 125 Vdc Station Battery Systems, 2018).

5.4 Incident Energy Design Thresholds

The incident energy must be designed to be as low as reasonably achievable. The DNSP shall have a design threshold of no greater than 8 cal/cm^2 to allow the use of Category 2 PPE. Aligning to the ATPV of regular workwear (8 cal/cm^2) for any given scenario will simplify management of arc flash hazards across each network.

Table 1: Incident Energy Level Design Thresholds

Target	ATPV Category	Energy Thresholds
Primary Target	Category 2	8 cal/cm^2
Secondary Target	Category 4	40 cal/cm^2 see footnote 2

[2] While Category 4 PPE is defined as meeting an ATPV of 40 cal/cm^2, advancements in materials science have increased the minimum benchmark to 50 cal/cm^2. To accommodate the broadest

Application of Category 4 PPE shall not be the first response to a high consequence scenario. The standard approach of Elimination, Substitution, Engineering, and Administrative controls must be considered before the use of Category 4 PPE as a risk control. Mitigation measures to meet these requirements shall be as per 7.2 Risk Assessment Controls. A clear record of the application of the hierarchy of control process shall be documented as per 7.2 Risk Assessment Controls before Category 4 PPE is used. Approvals will follow the process outlined in Section 5.8.

For details on EQL PPE refer to (Standard for Personal Protective Equipment (PPE) - 691352).

5.5 Translation of Incident Energy into Consequence

The incident energy level forms part of the results from an arc flash assessment. To apply this in an EQL risk assessment it is necessary to convert incident energy into a Health and Safety consequence that can be evaluated against EQL Risk Evaluation Matrix R056 Consequence (Health & Safety).

When translating incident energy into consequence, the assessor shall consider the clothing personnel will be wearing for the task being assessed. PPE must not be assumed to be absent unless the task is performed without arc-rated clothing. PPE selection remains a control measure within EQL controlled sites and must be verified as part of the risk assessment process. It is important to also consider the light, sound and pressure caused by the event.

The following table is provided as an *aide* in this direction. Selection of a consequence to align with EQL Risk Evaluation Matrix R056 is a subjective decision and will depend upon specific site conditions. This would form part of the risk assessment.

		Potential Consequence		
Energy Level Category	**Energy Level**	**No PPE**	**Cat 2 PPE**	**Cat 4 PPE**
1 – 2	4 cal/cm2 – 8 cal/cm2	Moderate Injury to Fatality	First Aid	First Aid
2 – 4	8 cal/cm2 – 40 cal/cm2	Permanent Impairment to Fatality	Medical Treatment to Permanent Impairment	First Aid
4	40 cal/cm2	Permanent Impairment to Fatality	Serious Injury, Permanent Impairment to Fatality	First Aid
> 4		Permanent Impairment to Fatality	Permanent Impairment to Fatality	Moderate Injury to Fatality

Figure 6: Incident Energy & Consequence

5.6 Assessment Method

Where Australian Standards do not exist, recognized international standards or methods will be use for the assessment of arc flash.

---

range of scenarios within the DNSP Category 4 PPE will be purchased with an ATPV rating of 50 cal/cm^2.

Table 2: Arc Flash Assessment Methods

System Type	Nominal Voltage	Method
AC Systems	Extra Low Voltage, and up to ≤ 207 V	HazChat
	Low Voltage, 208 V – 1000 V	(IEEE 1584, 2018)
	Medium Voltage 1001 V – 15 kV	(IEEE 1584, 2018)
	Above 15 kV	(ENA NENS 09, 2014)
DC Systems	Substation Batteries 24 V – 220 V	Deemed Category 1.[3]
BESS		(AS/NZS 5139, 2019)

5.7 Assessment Scope

An electrical installation may have several modes of operation. It is important to determine the available short-circuit current for the mode(s) of operation that provides both the maximum and minimum available short-circuit currents.

1. Establish credible operational modes up to N-1
2. Model system normal
3. Perform arc flash for system normal and each credible mode
4. Use worst-case results for HSE consequence.
5. Document scenarios, assumptions, & results

5.8 Approvals for Risk Assessments or JSEAs Considering Arc Flash Consequences

Where a Risk Assessment or JSEA considers Arc Flash consequences, the level of approval required is determined by the assessed risk level. Energy Queensland does not assign this approval to a single job role.

The (Enterprise Risk Management Standard R271 689958, 2023) and the (Risk Evaluation Matrix R056 - 691861, 2023) set out:

- How the risk level is calculated, and
- The level of organisational authority is required to endorse or tolerate that level of risk.

[3] The theoretical models used to predict arc flash incident energy for station batteries significantly overestimate the hazard. The test results by Bonneville Power Administration demonstrated that the maximum theoretical energy was not present. In the case of 125 V flooded lead-acid batteries, experimental results show that Category 1 arc flash PPE provides more than adequate protection. Refer Bonneville Power Administration (Arc Flash Hazards of 125 Vdc Station Battery Systems).

As risk levels increase, approval escalates through the management structure, as specified in those documents.

Therefore, the approving role for Arc Flash–related risks is the role identified in R271 and R056 for the assessed risk level. This ensures the decision is made by someone with the appropriate delegated authority under EQL's risk management framework.

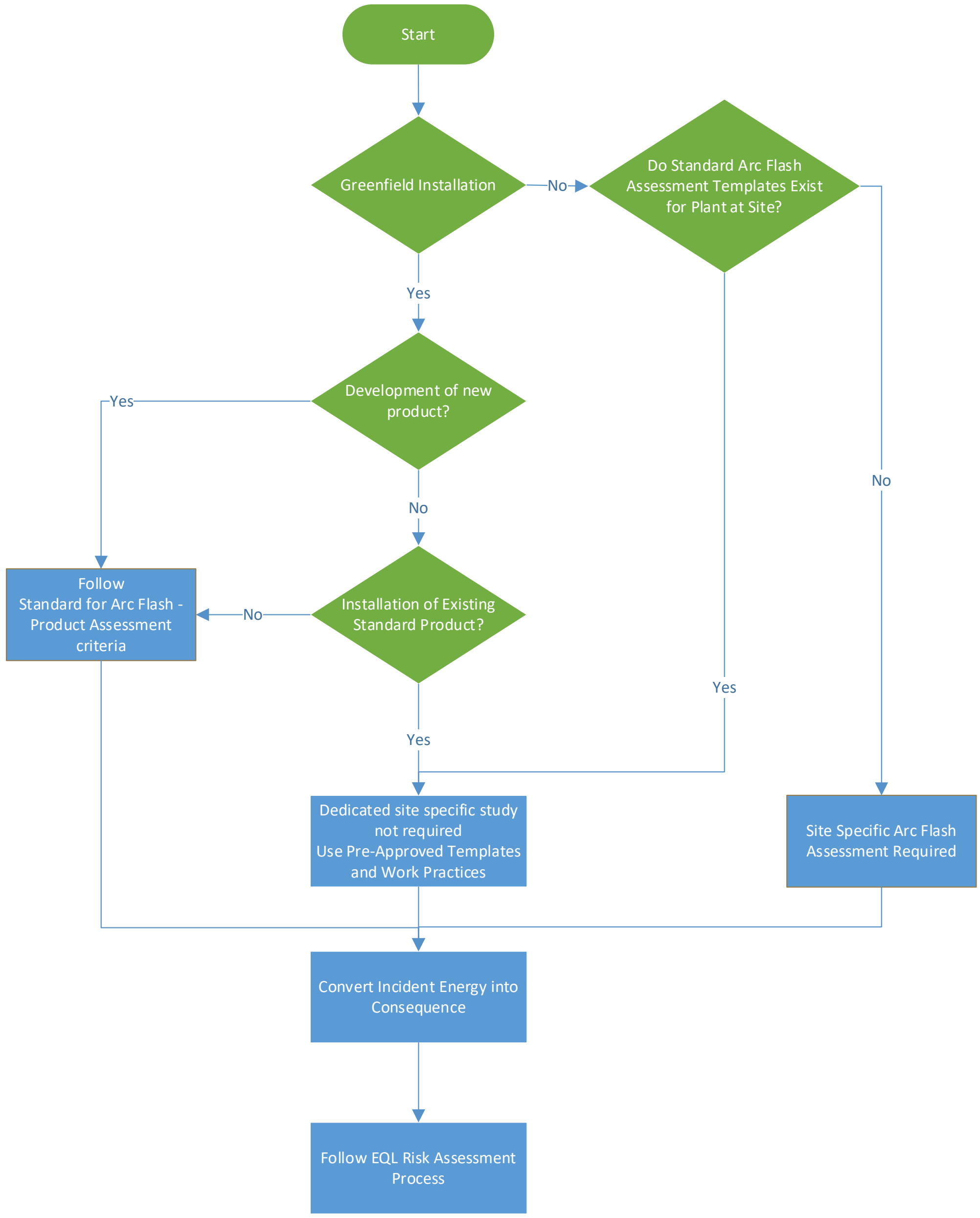

Figure 7: Arc Flash Assessment Process

6 Plant and Equipment Procurement

Energex and Ergon Energy use recognised Australian and International standards as part of their specification and technical evaluation for the procurement of switchgear to reduce the likelihood of injury from arc fault events.

6.1 Substation Switchgear and Switchboards

6.2 New Switchgear

All new switchgear shall meet the requirement of (Standard for Switchgear Selection, STNW 3051 - 12743722, 2023), with further details included within the appropriate technical specifications.

6.2.1 Internal Arc Containment in MV Switchgear

Internal Arc Classification (IAC) is an important factor in MV switchgear specifications to ensure worker safety. Understanding and implementation of the principles of IAC significantly reduces the likelihood of injury from arc fault events.

Modern equipment is designed with fault scenarios in mind. This equipment can be tested and certified to ensure that any escaping arc fault energy is contained or redirected, thereby reducing the risk of injury to personnel. Internal Arc Classification requirements defined in standards such as (AS 62271 Part 200) provide a clear framework for this.

IAC categories based on the accessibility and the level of arc protection provided:

- A Restricted to authorised personnel
- B Unrestricted, including the general public
- C Restricted by installation out of reach

The classifications also include directions (Front, Lateral, Rear) and test parameters (current in kA and duration in seconds). Tests ensure the switchgear remains safe under specified conditions, preventing hot gas leakage or projectile ejection that could harm nearby operators.

Since the 1990 edition of IEC 60298 and continuing with the updated (AS 62271 Part 200), switchgear standards have included test requirements for mitigating the effects from internal arcs to enhance operator safety. The standards ensure that all operations, including the transfer of withdrawable parts, can be performed without compromising the level of arc protection.

6.2.2 Low Voltage Switchboards Background

While medium voltage systems mandate extensive destructive testing to an Internal Arc Classification (IAC), low voltage systems adopt a different approach, focusing on segregation and form factors to achieve protection from arc flash.

Low voltage switchgear is designed to the AS/NZS 61439 series, which mandates protection against internal arcing fault currents by design. Instead, (AS/NZS 3000, 2018) Clause 2.5.5.3, Note 3 explicitly states that internal arc fault testing of switchboard designs to Annex ZD of (AS/NZS 61439.1, 2016) or (IEC/TR 61641, 2019) is not required. This note highlights that while such testing can enhance internal separation, it is not mandatory, as the focus is on design measures to prevent faults and contain arcs within compartments.

One of the primary methods employed in low voltage switchgear to prevent arcing faults is the use of internal separation. According to (AS/NZS 3000, 2018), switchboards must incorporate means to reduce the probability of initiating arcing faults. This can be achieved through insulation, barriers, or internal segregation of components. For instance, busbars are separated from functional units, and terminals for external conductors are isolated from the busbars. Segregation and insulation help prevent accidental contact with live parts and reduces the likelihood of arc flash events.

Forms of separation, such as Form 1, Form 2, Form 3, and Form 4, provide varying levels of protection and accessibility. For example, Form 1 has no internal separation, whereas Form 4 offers the highest level of segregation, ensuring that terminals of functional units are separated from each other. These forms are identified by specific ratings and methods, such as using metallic or non-metallic barriers, insulated busbars, and integral housing compliant with protection standards like IP2X.

6.2.3 Low Voltage Switchboards Requirements

All switchboards shall meet the requirements of:

- (AS/NZS 61439.1, 2016) Power switchgear and controlgear assemblies (PSC-Assemblies or PSC-A);
- (AS/NZS 61439.2, 2016) Distribution boards (DBOs); complying with (AS/NZS 61439.3).

Protection against electric shock from direct contact with parts, otherwise known as basic protection, shall be provided for all low voltage circuits as detailed in (AS/NZS 3000, 2018). New installations shall utilise any of the above basic protection options inside protection, control, and auxiliary panels where a door or cover is expected to be opened or removed during tasks such as testing, commissioning, maintenance, fault finding or refurbishment work inside the panel. For additional details refer (STNW3003).

Guidelines such as those within (AS/NZS 61439.1, 2016), Appendix ZC shall be followed to minimise the risk and effects of internal arcing faults. They focus on ensuring safety by preventing or controlling faults during normal operation. Manufacturers are required to implement design features that reduce the likelihood of internal arcs, while Energy Queensland preference assemblies that offer increased protection for both personnel and equipment.

The assembly shall be equipped to manage arcing faults. To achieve this, assemblies should incorporate insulated systems, compartmentalised busbars, and fault detection devices that rapidly interrupt arcing currents. Combining these design strategies helps prevent faults from escalating into major incidents, limiting both equipment damage and the risk of injury.

The incoming side(s) of all low voltage main switchboards, as well as other electrical systems below 1kV for a.c. and below 1.5kV for d.c., shall be equipped with integral voltage detection points. These detection points are to be designed to ensure that access to live exposed parts is not required for the specified tests listed.

For a.c. systems, the test points will enable phase-to-phase, phase-to-neutral, and phasing out operations, including checking phase rotation and voltages. For d.c. systems, the test points will allow testing of positive-to-negative and positive/negative-to-earth voltages. All test points will include protected 4 mm IP2x double insulated touch free banana plug sockets and be protected behind a suitably rated HRC fuse or circuit breaker.

Incident energy at the test point shall be kept as low as reasonably practicable and shall not exceed Category 2 (8 cal/cm^2). Test points shall be positioned so the person performing tests is not near other exposed live parts.

The location of test points shall be determined as part of a Safe by Design assessment undertaken during product development. This assessment shall include input from field representatives to identify the required test types and suitable test point locations. Test points are intended to support basic verification, commissioning, and operational checks and are not intended for detailed fault-finding activities.

6.2.3.1 Current Ratings ≥ 800 A

Along with measures specified in 6.7 Low Voltage Switchboards, Engineering controls shall be applied to limit arcing time, i.e., arc flash detection systems shall be installed at C&I substations.

Exceptions: –

1. Prefabricated substations (i.e., padmounts).

6.3 Metal Clad Switchgear

The switchboard shall be designed to conform with the internal arc withstand requirements of (AS 62271 Part 200, 2019), Annex AA. It shall be classified IAC-A, and FLR, at a test current of 25 kA for 1 second.

6.3.1 Circuit Breaker Truck Replacement

It is understood that switchgear without an IAC rating may not meet the same performance criteria as sites with modern equipment having an IAC rating. Where circuit breaker truck replacements are undertaken, measures shall be taken to provide the highest level of protection to personnel so far as reasonably practicable in case of an internal arc. These measures are aimed to limit the consequences of such an event. IAC type tested solutions, with new circuit breaker chamber doors that allow circuit breaker racking with the doors closed this shall be preferred where available.

When modelling arc flash scenarios generic values for circuit breaker operation times can be obtained from (Standard for Maintenance Acceptance Criteria - 2928929, 2023) - MAC. Existing in service equipment can be expected to at least meet C4 circuit breaker trip times. As such, replacement of bulk oil circuit breakers with vacuum circuit breakers will halve the trip time (from a desktop analysis perspective).

The following are some examples of these measures:

- remote operation instead of operation in front of the switchgear and controlgear;
- remote racking equipment
- rapid fault clearance times initiated by detectors sensitive to light, pressure or heat or by a differential busbar protection;
- pressure-relief device;
- transfer of a withdrawable part to or from the service position only when the front door is closed;
- fast elimination of arc by diverting it to metallic short circuit by means of fast-sensing and fast-closing devices.

The exact combination of these measures, or others not listed, that may be applied to a particular make and type of switchgear will vary.

An Arc Flash Hazard Assessment shall be undertaken as part of the scoping to identify deficiencies in meeting the criteria as defined within 5.2 Energy Level Target. Application of mitigation measures shall be as per 7.2 Risk Assessment Controls.

6.4 Distribution Network Plant

6.4.1 11 kV Padmount

11 kV Padmount substations shall be designed to conform with the internal arc withstand requirements of (AS 62271.202, 2019), Annex A. Prefabricated substations classified IAC-A, at a test current of 20 kA for 1 second at the 11 kV HV Switchgear Cable Box for authorised operators with doors open. In addition, the padmount substation shall also be tested under the same test current and duration to IAC-B with all doors closed, as a test for protection for the public.

6.4.2 22 kV Padmount

22 kV Padmount substations shall be designed to conform with the internal arc withstand requirements of (AS 62271.202, 2019), Annex A. Prefabricated substations classified IAC-A, at a test current of 20 kA for 1 second at the 22 kV HV Switchgear Cable Box for authorised operators with doors open. In addition, the padmount substation shall also be tested under the same test current and duration to IAC-B with all doors closed, as a test for protection for the public.

6.4.3 12 kV and 36 kV Ground-Mount

The high voltage cable box will be designed to conform with the internal arc withstand requirements of (AS 62271 Part 200, 2019), Annex A, A.2 Types of accessibility, Accessibility Type A, A.6 Acceptance criteria, Criterion No. 1 to Criterion No. 5 inclusive, for an IAC classification test current for each voltage level. The rated short time withstand current for each voltage level will be associated with an IAC Fault duration of 1 second.

6.5 Ring Main Units

6.5.1 RMU within Prefabricated Enclosure

Shall be designed to conform with the internal arc withstand requirements of (AS 62271.202, 2019), Annex AA. Prefabricated substations shall be classified IAC-B, at a test current of 20 kA for 1 second at the 11 kV HV Switchgear Cable Box.

6.5.2 RMU Within Indoor Rooms

Shall be designed to conform with the internal arc withstand requirements of (AS 62271.202, 2019), Annex AA. Standalone ring main units shall be classified IAC-A, at a test current of 20 kA for 1 second at the 11 kV HV Switchgear Cable Box.

6.6 High Voltage GIS Switchgear

The internal arc withstand of High voltage Gas Insulated Switchgear (GIS) from 66kV and above follows the standard IEC 62271-203, which specifically addresses the requirements for GIS. The switchgear must demonstrate compliance with the requirements of this standard, including the ability to withstand and safely manage the high-pressure and thermal effects of internal arc faults without endangering personnel. Considerations include enclosure design to contain the arc energy and effective pressure relief systems to direct exhaust gases safely.

6.7 Product Assessment

Arc flash hazard assessment shall be undertaken in multiple stages as part of product development.

1. During the preparation of the tender specification to determine if part, or parts of, the intended design will exceed Category 2. Any mitigation measures shall be included in the overall product specification to ensure compliance with this standard.

2. Evaluation of tender responses to ensure product compliance with design intent.
3. After tender award, and during product development / deployment to validate initial calculations and create any required arc flash equipment category data needed.

The standard (IEEE 1584.1, 2022) states:

> *Actual data on working distances, conductor gaps, or enclosure opening sizes may not be available in some cases, such as when conducting a preliminary study in the design stage of a new facility where the exact electrical equipment to be used has not been selected, or in an existing facility where in-service equipment cannot be opened.*

Where conductor gaps, or enclosure opening sizes are not available they shall be modelled using standard values for the appropriate voltage rating from Table 8 of (IEEE 1584, 2018).

Where an arc flash incident energy level is greater than Category 2, a hazard management strategy shall have prior review and endorsement by a person responsible for the activities to the hazard, and a person also having an appropriate authority to tolerate the risk on behalf of the organisation.

Tasks at locations that expose workers to greater than Category 2 shall be recorded within the appropriate corporate system.

For other assessment methodologies, such as DC arc-flash calculations, equivalent default values or modelling assumptions shall be applied following the guidance of the relevant standard or method.

Although AC equipment represents the highest priority within our business, the process of arc-flash assessment—whether AC or DC—requires a documented and iterative refinement. Preliminary assessments can use reasonable default values and clearly documented assumptions, with these inputs progressively updated and validated as design information becomes available. It is not acceptable to omit an assessment on the basis that exact equipment parameters are not yet known.

7 Arc Flash Hazard Assessment

For new and existing installations, the target arc flash hazard category is as low as reasonably practicable and not above Category 2 (8 cal/cm^2). The engineering methods below are recommendations to reduce the arc flash event 'consequence' rating.

7.1 Hazard Assessment

The arc flash hazard assessment is required to inform any immediate actions (whether temporary or permanent) to reduce the arc flash hazard to an acceptable level. Arc flash hazard mitigation must be implemented for all installations with an arc flash hazard rating of above Category 2, or locations as deemed necessary as an outcome of the risk assessment.

An arc flash hazard assessment should be performed prior to work on or near an equipment with arc flash hazard. The arc flash hazard assessment constitutes three key steps:

1. To identify the arc flash hazards and its severity. An objective measure of the consequence rating of an arc flash event is by incident energy level (cal/cm^2), but also considering the light, sound and pressure caused by the event.
2. To estimate the likelihood of occurrence rating of an arc flash event based on the work activities on or near the equipment of concern and the condition of the equipment refer (Standard for Classifying the Condition of Network Assets 2948464), as well as any work practices or training around existing controls when working live.
3. To determine if additional protective measures, operational practices, or mitigation controls are required to carry out the work on or near the equipment of concern, including the use of Arc Rated PPE.

7.1.1 Normal and Abnormal Operating Conditions

A normal operating condition exists when all the following conditions are satisfied (IEEE 1584, 2018):

- The equipment is properly installed.[4]
- The equipment is properly maintained.[5]
- The equipment is rated for the available fault current.
- The equipment is used in accordance with instructions included in the listing and labelling and in accordance with manufacturer's instructions.
- The equipment doors are closed and secured.
- All equipment covers are in place and secured.
- There is no evidence of impending failure.[6]

[4] The phrase 'properly installed' means that the equipment is installed in accordance with applicable industry codes and standards and the manufacturer's recommendations.

[5] The phrase 'properly maintained' means that the equipment has been maintained in accordance with the manufacturer's recommendations and applicable industry codes and standards.

[6] The phrase "evidence of impending failure" means any indication of developing defects, including physical signs such as arcing, overheating, loose or bound equipment, or adverse results from diagnostic testing (e.g. partial discharge or other condition-monitoring tests).

Where one or more of these conditions are not met the equipment is deemed to be in an abnormal operating condition and a higher likelihood of arc flash hazard exists. Such situations should be assessed as per section 5.3 Methodology and section 7.2 Risk Assessment Controls, taking into account the increased likelihood.

7.2 Risk Assessment

Arc flash hazard assessments provide a quantified consequence (incident energy level), but do not account for likelihood or existing control measures. Therefore, the consequence must be integrated into a broader risk assessment process in accordance with:

- (Risk Management Procedure - 9937852, 2023)
- (Job Safety and Environmental Analysis Framework – 690212, 2024)

7.2.1 Risk Assessment Integration

The following steps shall be undertaken to ensure consistent and auditable risk assessment:

1. **Consequence Determination**

   Use the incident energy level (cal/cm²) from the arc flash study to determine the consequence rating using (Risk Evaluation Matrix R056 - 691861, 2023).

   Considerations and additional factors:

   - Light, sound, and pressure effects
   - PPE and controls as per existing work practices
   - Egress constraints, such as limited escape routes, restricted movement, or confined spaces that may increase injury severity

2. **Likelihood Estimation**

   Assess the likelihood of arc flash occurrence based on:

   - Equipment condition (refer to Standard for Classifying the Condition of Network Assets – 2948464)
   - Operating environment (normal vs abnormal conditions per IEEE 1584)
   - Task type and frequency
   - Historical data and incident trends
   - Recent test or diagnostic results (e.g. partial discharge, infrared, ultrasonic, insulation testing)
   - Evidence of impending failure

3. **Control Identification and Effectiveness**

   Identify existing controls and assess their effectiveness using the Control Effectiveness Rating (Poor/Average/Good) as per Risk Management Procedure. Controls may include:

   - Engineering controls (e.g., arc flash detection, remote operation)
   - Administrative controls (e.g., training, procedures)

- PPE (as a last resort)

4. **Risk Evaluation**

   Combine consequence and likelihood to determine the risk level. Evaluate whether the risk is within EQL's appetite or requires further treatment.

5. **Risk Treatment and Endorsement**

   Where risk is intolerable or above appetite:

   - Apply the hierarchy of controls (elimination, substitution, engineering, administrative, PPE)
   - Document justification for control selection
   - Obtain endorsement from a responsible Technical Authority and Risk Owner

6. **Documentation and Assurance**

   All risk assessments must be documented in the JSEA worksheet and stored in accordance with the JSEA Framework. Assurance activities must verify that controls are implemented and effective.

7.3 Potential Control Measures

The below control measures outline a systematic approach to reduce arc flash incident energy and the required PPE level. The list of control measures below is not exhaustive and mitigation comprising a combination of control measures or other control measures not listed below may be required.

Control measures shown in order of assessment preference:

- Substitution – Work deenergised
- Engineering control – Network reconfiguration
- Engineering control – Adjust protection settings
- Isolation – Remote operation, equipment and worker segregation
- Engineering control – Longer equipment operating handles or test probes
- Engineering control – Install arc flash detection
- Engineering control – Arc fault current limiting
- Engineering control – Maintenance mode
- Engineering control – Zone selective interlocking
- Substitution – Switchboard renewal with AFLR rated switchboard
- Engineering control – Arc Quenching
- Elimination – System redesign, reduce arc energy (fault current)
- Administrative – Training, safe work policies and procedures.

7.3.1 Network Reconfiguration (Engineering Control)

3Φ bolted fault current plays a critical role in determining arc flash incident energy. Prospective fault currents can be reduced by alternate network arrangement; therefore, network reconfiguration is a mitigation measure is to the to reduce the fault current and then arc flash incident energy. Examples of this might be using remote switching to open a bus section circuit breaker or transformer circuit breaker for only the duration of the task. However, reducing fault current can increase protection relay clearing times, hence increasing incident energy. Arc flash incident energy calculations are necessary to confirm the effects.

7.3.2 Protection Device Selection and Setting Review (Engineering Control)

Arc flash incident energy can be greatly reduced by selecting appropriate protection devices and protection settings.

A protection setting review may be undertaken to ensure the settings operate as fast as possible, maintaining time and current coordination between protection devices and avoiding risk of nuisance tripping.

For LV switchboards the incoming protection can only be relied upon to achieve the desired category rating downstream of the protection device. All electrical components up to the incoming protection to which a person may be exposed to an arc flash will need to be fully insulated or phase, phase/ earth barriered to maintain the arc flash rating of equal to or less than that provided by the incoming protection.

The plasma from an arcing fault within the switchboard can move in unpredictable ways and may move to involve the line side terminals of the incoming protection device. This negates any fault clearing capability the switchboard incoming protection provides. Where this fault type is possible the arc flash hazard category must be based on the next upstream protection device.

7.3.3 High Risk Arc Flash Mitigation (Engineering Control)

For installations that return an intolerable risk after assessment, the option of temporarily sacrificing protection discrimination grading (whether completely or partially) to reduce the arc flash hazard to an acceptable level, until a long-term mitigation strategy is implemented, may be considered.

7.3.4 Remote Operation (Isolation)

Remote operation means operating switchgear outside the arc flash boundary in which the switchboard is located, using an HMI or lanyard control cable.

HMI or plug in lanyard remote operation controls can be used for isolating and energising equipment, removing the operators from potential exposure to high incident energy levels.

7.3.5 Arc Flash Detection (Engineering Control)

Arc flash detection systems that utilise light sensors, with provisions to protect against mal operation.

Where fitted, arc flash detection current transformers (CTs) must be located on the line side of the incomer protection device as a current check to prevent inadvertent operation.

Arc light sensors must be accessible for maintenance and installed as per the manufacture's requirements.

7.3.6 Arc Fault Current Reduction (Elimination)

Either current limiting fuses or circuit breakers can be used. The design must ensure that the protection device specified will operate in its fault current limiting range under minimum arcing fault current conditions.

The performance of fuses for limiting the peak value of prospective bolted fault current is generally better than that of fault current limiting circuit breakers.

If current limiting fuses are chosen for mitigation, additional labelling stating fuse type and ratings are required on the switchboard to clearly designate the use of current limiting fuses. The design will need to show all calculations to ensure the fault limiting fuses are carrying out there intended use.

7.3.7 Maintenance Mode (Engineering Control)

Maintenance Mode schemes can be used for HV and LV protection devices to reduce the incident energy during activities where staff can be in the arc flash boundary or working distance. A switch, or similar, remotely activates the “Maintenance Mode” on the protection device, reducing the instantaneous current and delay time, whilst raising an alarm to the SCADA system.

7.3.8 Zone Selective Interlocking (Engineering Control)

Zone selective interlocking between backup, primary and outgoing feeder protection uses blocking signals which are sent between downstream and upstream protection devices, allowing protection to trip quickly without a protection grading trade off.

7.3.9 Switchboard Renewal (Substitution)

The option to renew an existing switchboard to mitigate/reduce the arc flash hazard assessment ‘likelihood’ rating to reduce the overall risk rating can be considered subject to the outcome of the installation condition assessment and other site requirements.

Note:

- The arc flash hazard assessment ‘consequence’ rating is irrespective of the age or condition of the installation. Often, design elements within the existing switchgear are the major contributors towards the consequence due to the tasks workers need to perform i.e. racking withdrawable switchgear. Renewal of a switchboard only mitigates/reduces the risk ‘likelihood’ rating unless the new switchgear removes or substantially modifies these elements. e.g. new fixed pattern switchgear replacing withdrawable switchgear, CB truck replacement with new doors to allow racking with doors closed. Conversely, like for like replacement of only a withdrawable LV air circuit breaker is unlikely to alter the consequence.
- A switchboard that is ‘aged’ (e.g. passed its Design Life however with Remaining Life before the asset is unusable), and non-compliant to the current standards should not be used as the sole justification for renewal of an existing switchboard.

7.3.10 Arc Quenching (Engineering Control)

Used in conjunction with an arc flash detection system to clear an arcing fault within a few milliseconds. An arc flash quenching device extinguishes an arc much faster than a circuit breaker by causing a rapid bolted short circuit between phases or between phases and earth close to the arcing fault location. This causes a collapse in the arc voltage, rapidly extinguishing the arc. The bolted short circuit current flows through the quenching device until it is interrupted by the upstream protective device.

Arc quenching devices are available for both HV and LV switchboards. For LV switchboards the available quenching devices are relatively compact and can be incorporated into the switchboard being protected, if the bolted fault withstand rating of the board is adequate. If the board cannot safely sustain a bolted fault, then the quenching point can be installed upstream of the board.

7.3.11 Distance (Engineering Control)

Use of tools or modified work practices to move the worker further away from the source of the arc flash event.

7.3.12 DC Battery System Controls (Engineering Control)

For DC battery installations within 24 V to 220 Vdc (including 48 V telecommunications systems and 110/125/220 V substation batteries), the following engineering controls should be considered in addition to the measures above:

- Terminal shrouding and insulated bus covers.
- Segregation barriers between positive and negative conductors.
- String-level fusing or DC-rated circuit breakers installed as close as practicable to the source.
- Protective devices with DC interrupting capacity suitable for the prospective fault current.
- Touch-safe test points for routine measurements.

8 Arc Flash Boundary

The arc flash boundary is the distance from live parts within which a person without Arc Rated PPE could receive a second-degree burn. Outside of the arc flash boundary the assessed energy levels are below 1.2 cal/cm^2 (i.e. within the arc flash boundary the energy levels are 1.2 cal/cm^2 or above). The software evaluation tool automatically determines the arc flash boundary.

Energy Queensland will apply a uniform 3 m Arc Flash Boundary, which also aligns with working near definition under the Electrical Safety Act. This will not be delineated on the floor of substation rooms, as the same measures cannot be uniformly applied across the complete distribution network. i.e. padmounts, and link pillars.

9 Signage and Labels

Warning labels shall be provided on electrical enclosures where workers may access internal compartments or remove covers, and an arc-flash hazard may be present.

This includes low and medium voltage switchboards and DC battery systems (24 V to 220 Vdc) such as battery rooms, cabinets, stands.

For switchboards, warning labels located on the front of the switchboard must be produced to inform workers of the potential arc-flash incident energy level and the required PPE when working on various parts of the switchboard.

There should only be one pair of labels (Danger & Arc Flash PPE) for each switchboard, it is preferred the label is installed near the incomer(s). The arc flash warning label is showing the worst-case arc flash consequence at various location of the switchboard irrespective of the work activities.

For DC battery rooms and DC distribution enclosures, equivalent warning labels shall be installed at the points where staff access the equipment (e.g. doors, covers).

If an existing Danger sign is already present on the switchboard or equipment, the Danger component of the label may be omitted.

For installations with facility for a mobile generator connection, a separate warning label must be provided at the generator connection point and switchboard generator circuit breaker panel highlighting the basis for sizing the mobile generator alongside the resultant arc flash hazard rating associated with the mobile generator operation.

Symbols shall be in accordance with (AS 1319, 1994).

9.1 Danger Label

The information required for the Danger label shall be as per (AS/NZS 4836, 2023) and Energy Queensland Labelling Specification.

Figure 8: Danger Sign Arc Flash and Shock Hazard Label

9.2 Arc Flash PPE Label

The information required for the arc flash label must generally align with (AS/NZS 4836, 2023) and Energy Queensland Labelling Specification. The following information must be included on the arc flash warning label:

- Site name
- Location description of the switchboard
- Nominal voltage of the switchboard
- PPE requirements (Category Number)

9.2.1 Interim Labels

Interim labels shall be as per (AS/NZS 4836, 2023) Section B11.

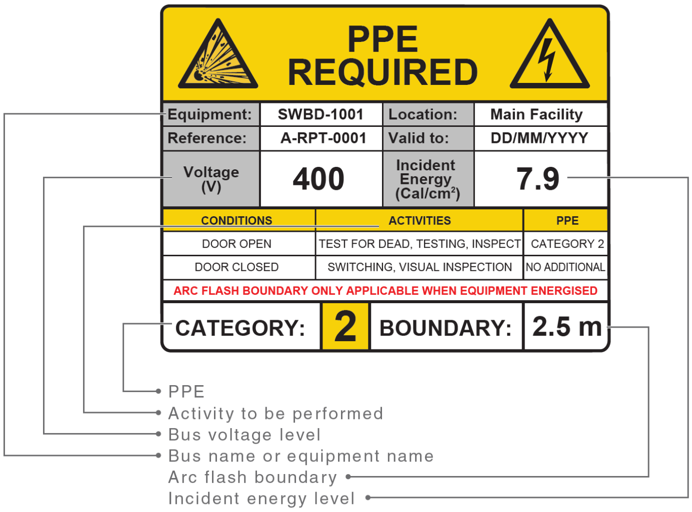

Figure 9: Arc Flash PPE Label - Initial

9.2.2 Future Labels

As part of best practice, arc flash energy calculations should be reviewed at least 5-year intervals. Due to the size of the Energy Queensland network, it is more practical if the labels are independent of variables or data that may change over time. Future labels will include QR codes to resolve this issue with any data that may change being stored in back-end IT systems.

Workflows for field staff might include scanning a QR code on plant to retrieve site/plant item specific data. The QR code would identify the plant item, and its location within the network. Should fault levels change through network augmentation, the back-end data would change, therefore keeping the site data automatically up to date. This also introduces the possibility to also link to switchgear operating manuals via the same QR code.

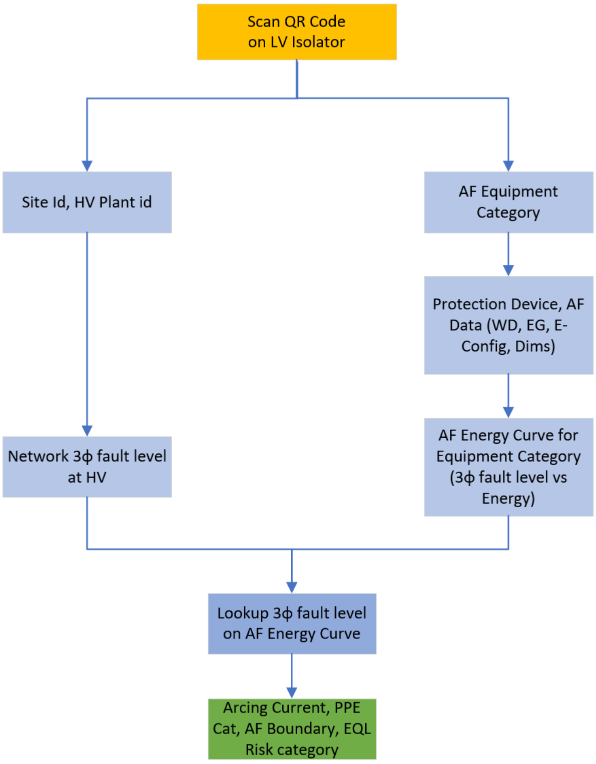

Figure 10: Potential QR Code Workflow

9.2.3 Non-Standard Fusing Labels

EQL is sometimes requested to review our protection settings at a site to reduce the incident energy at a customer's switchboard. This may involve installing non-standard, smaller sized fuses on the fused unit at a HV RMU. Where this situation occurs, Warning labels shall be installed on the RMU to advise staff standard fusing practices will not apply at this transformer.

9.2.4 Label Exclusions

The following locations will not have arc flash PPE labels installed.

- Outer Doors of Padmount/Kiosk Transformers.
- Low Voltage pillars
- Low Voltage pits.
- Low Voltage links or bridging on the overhead network.

9.2.5 DC Battery System Labels

DC battery banks, battery isolation devices (circuit breakers or fuses), rectifier/charger DC distribution equipment, and DC distribution frames within 24 V to 220 Vdc shall be provided with warning labels where staff may access enclosures or remove covers.

Labels shall include:

- Site name or cabinet identification
- System nominal voltage
- Battery system purpose (e.g. telecommunications supply, substation supply)

- Prospective short-circuit current (if known)
- Required PPE category (including Deemed Category 1, where applicable)
- A DC-specific hazard statement indicating high fault current and the risk of tool-bridging or molten-metal ejection.

Where QR code workflows are adopted, DC hazard information shall be included in the back-end data set for the DC system.

10 Corporate IT Systems and Arc Flash Data

10.1 Asset Tracking

The switchgear geometry information required to calculate incident energy to (IEEE 1584) and other standards shall be stored in a corporate database system.

10.2 Works Planning

Where PPE with a higher rating than the general uniform is required, information on the required PPE rating should be available in corporate systems such as DMA and GIS. This supports proper planning before staff arrive on site.

Annex A

Informative

Site Specific Arc Flash Assessments

A.1 Site Specific Arc Flash Assessments

The Annex describes methods used for a.c. arc flash analysis from 200V – 15,000V according to IEEE Std 1584:2018. It has been included here are as it covers the broadest range of activities undertaken within the EQL business. Whilst the methodologies for arc flash analysis of other systems may differ, the greater concepts (incident energy, boundaries etc) from IEEE Std 1584 arc flash analysis are transferable.

A1.1 IEEE Std 1584 Arc Flash Analysis Method

The outcomes of an (IEEE 1584, 2018) arc flash analysis method are as follows:

Incident energy at the working distance

The incident energy is the amount of energy a surface (or a person's face and chest) exposed to an arc flash will experience at a set distance (known as the working distance) from an arc. The incident energy reduces exponentially as the distance between the person and the arc source increases.

A1.2 Arc Flash Boundary

The arc flash boundary is the distance from live parts within which a person without Arc Rated PPE could receive a second-degree burn. Outside of the arc flash boundary the assessed energy levels are below 1.2 cal/cm^2 (i.e. within the arc flash boundary the energy levels are 1.2 cal/cm^2 or above). The software evaluation tool automatically determines the arc flash boundary.

A1.3 Hazard Rating Category

Once the incident energy has been assessed a Hazard Rating Category can be assigned. (AS/NZS 4836, 2023) defines four Hazard Rating Categories (Category 1 – 4), according to specified ranges of incident energy.

A1.4 Arc Flash Analysis Locations

Within a switchboard the arc flash incident energy can be different at each location due to combinations of different protection devices (with a different operating times) acting to interrupt the arc, and geometry of the switchboard. Analysis must first be undertaken to determine potential work tasks, and their locations. Arc flash calculations must be undertaken at multiple locations to determine the worst-case scenario.

Potential 'worst-case' incident energy.

Location 1 – Incomer terminals on the line side of the incomer protection.

Location 2 – Terminals, main busbars and droppers located between the main incoming protection and the outgoing feeder protection.

Location 3 – Feeder terminals on the load side of the outgoing distribution feeder protection.

A1.5 Arc Flash Calculations Steps

The following steps must be completed when performing an arc flash analysis:

- Collect the system and installation data
- Prepare a software model of the electrical system
- Assess the duration of the arcing fault
- Identify work tasks
- Identify working distances from work task
- Determine the normal and abnormal operating scenarios, including alternate supply arrangements
- Calculate the incident energy for all valid scenarios
- Determine the arc flash boundary
- Produce arc flash report

A1.6 Data Gathering

For each electrical equipment or plant area under assessment the data required for modelling the electrical system to carry out arc flash incident energy level assessments is detailed in the following sections which includes:

- Transformer, mobile and permanent generator data
- Cable data
- Switchboard types e.g. arc rated, form 3b, IAC categories A-FLR
- Cubicle / Panel dimensions
- Protection device details and settings
- Determine the bus gaps
- Electrode configurations
- All assumptions must be detailed in the report.

A1.7 Permanent and Mobile Generators

The following information must be modelled for generators:

- Rated voltage
- kVA rating
- Rated power factor
- D-Axis sub-transient reactance (Xd”)
- Stator resistance (Rg)
- Earth connection details

Note:

1. For installations with facility for connection of a mobile generator, the arc flash assessment must consist of a minimum generator rating (with typical sub-transient and resistance parameters) that satisfies the performance requirements of the installation.
2. Typical fault current contribution from mobile generators can be significantly less the normal supply networks. This may impact clearing times, and hence incident energy.

A1.8 Transformers

The following name plate information must be modelled for transformers:

- Voltage ratings
- Winding connections
- kVA rating
- Tap position
- Positive sequence transformer impedance (%Z)

A1.9 Cables

All cables from the point of supply up to the bus bars of the switchboards under assessment, as well as any other sources of fault current including generators and induction motors that would contribute fault current in the event of an arcing fault, including induction motors downstream of the board under assessment must be modelled.

The following information must be modelled for cables:

- Conductor size
- Conductor resistance and reactance values
- Number of conductors in parallel
- Conductor length

For LV cables the resistance and reactance values of cables can be obtained from the manufacturer technical catalogues or (AS/NZS 3008.1.1, 2017).

A1.10 Protection Device Characteristics

Protection device settings must include:

- The time current characteristic settings of the protection device
- The upper and lower operating time tolerance bands of the time current tripping characteristic

Note:

Based on the ‘worst-case’ assumption that arcing faults quickly escalate into three phase balanced faults, earth fault protection cannot be relied upon to clear an arcing fault. Thus, modelling of earth fault protection devices is not a requirement for arc flash assessment.

When sensitivity modelling arc flash scenarios, generic values for protection device operation times can be obtained from (Standard for Maintenance Acceptance Criteria - 2928929).

e.g. Task. Preform a generic arc flash hazard analysis for rackable medium voltage switchgear. In Energy Queensland there will be many new and legacy protection devices. When undertaking generic arc flash studies it is acceptable to use MAC C4 data for relay operating time. Therefore, if the switchgear is protected by a bus zone scheme it is possible to use the C4 operate time for a bus zone relay from the MAC. All in service relays will meet these criteria. Similar techniques shall be applied to other devices in the tripping path, i.e. high speed tripping relays.

A1.11 Circuit Breakers

When modelling arc-flash scenarios, generic values for Circuit Breaker Mechanical Opening Time may be used where test data is unavailable.

For MV circuit breakers, mechanical opening times shall be obtained from the (Standard for Maintenance Acceptance Criteria - 2928929) - MAC. It is acceptable to use MAC C4 data for circuit breaker mechanical opening time.

Where tested circuit breaker mechanical opening time differs from MAC values:

- If shorter (better) than MAC, the MAC standard tripping time shall be used for system modelling.
- If longer (worse) than MAC, the tested tripping time shall be used for system modelling. Typical application scenario, NAR applied to group of circuit breakers based on new testing data.

For LV MCBs, LV MCCBs, and LV ACBs with integral trip units, the manufacturer's time–current characteristic already includes internal mechanical opening and arcing time. These values shall not be added separately when calculating clearing time.

Table 3: Circuit Breaker Mechanical Opening Time

Device Type	Typical Mechanical Opening Time	Recommended Value
LV MCB (Miniature Circuit Breaker)	Included in manufacturer TCC	Do not add separately
LV MCCB (Moulded Case Circuit Breaker)	Included in manufacturer TCC	Do not add separately
LV ACB (air circuit breaker)	Included in manufacturer TCC unless using separate relay	If integral trip unit: do not add If separate relay: use 50 ms
MV Oil Circuit Breaker	varies	MAC C4
MV Vacuum Circuit Breaker	varies	MAC C4

A1.12 Arcing Time

Arcing Time varies depending upon circuit breaker voltage, type, and interruption medium. The values in Table 4 represent typical arc-extinguishing times after contact separation and are intended for use in arc-flash studies.

Table 4: Arc-Extinguishing Time After Contact Separation

Device Type	Typical Arc-Extinguishing Time After Contact Separation	Recommended Value
LV MCB (Miniature Circuit Breaker)	Included in manufacturer TCC	Do not add separately
LV MCCB (Moulded Case Circuit Breaker)	Included in manufacturer TCC	Do not add separately
LV ACB (air circuit breaker)	10–30 ms (only if separate relay)	If separate relay: 30 ms
MV Oil Circuit Breaker	20–50 msec	50 msec
MV Vacuum Circuit Breaker	10–20 msec	20 msec

A1.13 Calculation of Clearing Time in PowerFactory

PowerFactory calculates Protection Operating Time based on the configured protection functions, relay settings, and fault conditions.

For arc-flash and protection studies, the Clearing Time shall be determined by combining the protection operating time obtained from PowerFactory with additional device and system-related time components, in accordance with the definitions in this document.

Depending on the protection philosophy and system configuration, the applicable clearing time shall be determined as Clearing Time (Local), Clearing Time (Remote), or an effective clearing time consisting of a sequence of coordinated local and remote clearing actions.

A.1.13.1 Clearing Time (Local)

Where a fault is cleared by operation of the local switching device, the clearing time shall be calculated as:

Clearing Time (Local) =

Protection Operating Time

+ Interposing Relay Operating Time (where applicable)

+ Local Circuit Breaker Mechanical Opening Time

+ Local Circuit Breaker Arcing Time

Protection operating time shall be obtained directly from PowerFactory.

Interposing relay operating time, circuit breaker mechanical opening time, and arcing time shall be specified by the user using device-appropriate values selected in accordance with Sections A1.11 and A1.12, or MAC values where applicable.

Where interposing relays are not installed, interposing relay operating time shall be taken as zero.

A.1.13.2 Clearing Time (Remote)

Where a fault is cleared by operation of a remote switching device, including schemes utilising intertripping, the clearing time shall be calculated as:

Clearing Time (Remote) =

Protection Operating Time (sending end)

+ Intertrip Transmission Time

+ Interposing Relay Operating Time (where applicable)

+ Remote Circuit Breaker Mechanical Opening Time

+ Remote Circuit Breaker Arcing Time

Intertrip transmission time shall include all communications, processing, and receiving-end control circuit delays between generation of the remote trip command and energisation of the remote circuit breaker trip device.

A.1.13.3 Effective Clearing Time

Where fault clearance is achieved by a sequence of coordinated local and remote clearing actions, the effective clearing time shall be taken as the total elapsed time from fault inception to final arc extinction on the primary system.

The effective clearing time shall be used for arc-flash incident energy calculations.

A.1.13.4 Circuit Breaker Modelling

For modelling purposes, circuit breakers may be grouped by device class in accordance with Sections A1.11 Circuit Breakers, A1.12 Arcing Time, and MAC, where applicable.

For each installation, a circuit breaker representative of the installed equipment shall be selected. The circuit breaker mechanical opening time and arcing time entered for modelling shall correspond to the selected device class.

Where a protection device comprises a circuit breaker with an integral trip unit, the time-current characteristic provided by the manufacturer typically represents the combined protection operating time and mechanical opening time.

Where the protection relay and circuit breaker are separate devices, the circuit breaker mechanical opening time shall be specified as a separate modelling parameter.

The total clearing time derived using this method shall be used for arc-flash energy calculations.

A1.14 Switching Points

The model must include all switching points which could affect the fault current levels, within the site boundary. This includes HV and LV switching points such as:

- Bus-ties
- Isolation points for contingency supply arrangements

A1.15 System Buses

The nominal operating voltage must be included in the model for all busses and terminals.

A1.16 Plant Considerations

The electrode configuration that applies in any given scenario will depend on where the worker is positioned in relation to the bus.

Consider the following: –

Table 5: Plant Considerations[7]

Plant Item	Consideration
Low Voltage Switchgear	LV switchgear installations may have all three enclosed configurations present. VCB and VCBB can be present when the circuit breaker is in a cubicle. HCB may be present when a circuit breaker is removed from a cubicle and the circuit breaker stabs are exposed and pointed towards the worker. When the rear of switchgear is exposed, VCB, VCBB or HCB may be present depending on the bus insulation and orientation of conductors with respect to the worker
Panelboards	Low voltage panelboards and load centres may have VCB or VCBB present. VCB may be present when an arc is initiated and travels to the bottom of the main vertical bus. VCBB may be present if a moulded case circuit breaker acts as a barrier at the vertical bus. It is unlikely that an HCB fault will occur within a panelboard because there is no significant horizontally oriented bus. There may be small pieces of horizontal bus that appear to point towards the opening (such as bolt heads or terminations), but they are likely not long enough to redirect the arc plasma horizontally towards the enclosure opening.
Low Voltage Switchboards	Low voltage switchboards have feeder sections that are similar to panelboards and may have VCB or VCBB present depending on whether a circuit breaker acts as an insulating barrier. It is unlikely that an HCB fault will occur within a switchboard feeder section because there is no significant horizontally oriented bus, similar to a panelboard. At a switchboard main incoming compartment, there may be horizontal runs of bus that appear to be HCB, but the bus spacing is typically greater than the upper limit of the gap range of model. Therefore, for a typical switchboard, HCB may be ignored.
Low Voltage Disconnect Switches	Low voltage disconnect switches (fused or non-fused) may have VCB or VCBB present. VCB may be present when an arc is initiated at the vertical bus within the switch. VCBB may be present if a fuse or other device acts as an insulating barrier at the vertical bus. Even though small conductors such as fuse clips appear to be pointed towards the opening, they are not likely to be long enough to redirect the arc plasma towards the worker.
Low Voltage Motor Control Centres	Typical motor control centres panels have an overcurrent protective device that may have VCB or VCBB present depending on where the arc is initiated relative to an insulating barrier. HCB is not likely to be present within an individual motor control centre enclosure because there is typically no horizontal conductor that would be pointed at the worker. Opening the rear compartments of a motor control centre is likely to expose vertical runs of bus that are not likely to point towards the worker in an HCB manner.

[7] A Practical Application of IEEE STD 1584-2018 IEEE Paper No. PCIC-2021-54

Plant Item	Consideration
Medium Voltage Equipment	In addition to VCB and VCBB conductors, medium voltage switchgear and switches are more likely to have horizontal bus runs that will behave like an HCB fault. Withdrawable Circuit Breakers can be modelled in the following way. Horizontal:- as HCB Vertical:- as VCBB
Open Air Configurations	Equipment with exposed energised parts in open air can also have orientation that is either vertical or horizontal. The electrode configuration that applies will depend on where the worker is positioned in relation to the bus. For example, standing underneath a vertical bus will expose the worker to HOA. Because open air exposed energized parts can be accessed from a variety of positions, it may be prudent to consider the HOA configuration in most cases.

IEEE 1584 - 2018

Table 9—Correlation between actual equipment and electrode configuration

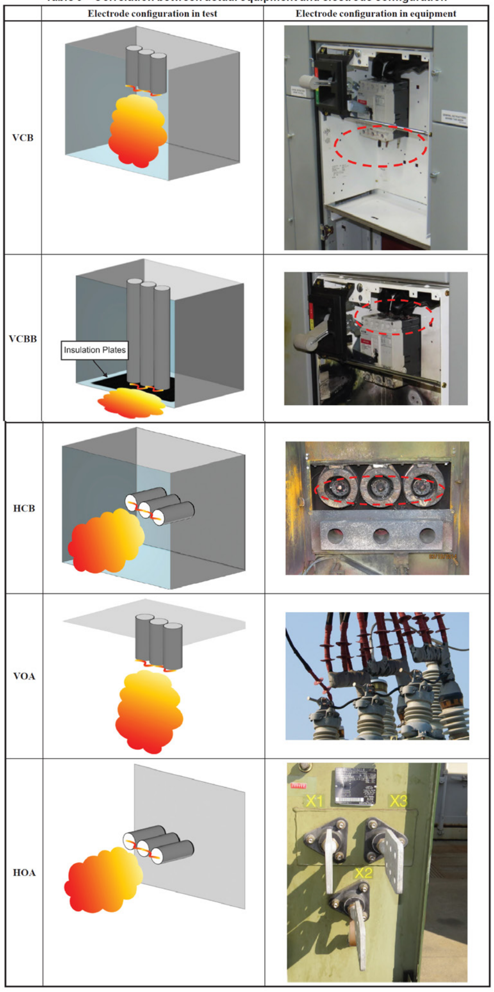

Figure 11: IEEE 1584:2018 Electrode Configurations

Annex B

Informative

Arc-Flash Hazard Calculation Study Report

B.1 General Principle

As a general principle any Arc Flash report should have sufficient information within to allow recreation of the analysis later should there be the need.

B.2 Arc-Flash Report

The arc-flash hazard report shall be in electronic format. The general intent shall be that sufficient information shall be included in the report to enable a new model to be created from the data, should there be a need in the future.

The following information is to be included in the report:

- Executive summary
- Scope
- Methodology used, including:
  - Other system studies that may have been utilised or performed in conjunction with performing the arc-flash hazard calculation study such as: short circuit and equipment evaluation studies and overcurrent protective device coordination studies
  - Basis of study, including assumptions
  - Results of the study
- Description of modes of operation of the system and details of the modes evaluated.
- All applicable protective devices within the scope of the study.
- Arc-flash results: A tabulated form or spreadsheet including a listing of all electrical equipment that had arc-flash hazard values calculated as part of the analysis, specifying to which operating modes the results apply.
- For each location, include information as applicable:
  - Equipment identification
    - The three phase rms symmetrical bolted fault current from the short circuit study
    - The calculated arcing current
    - Identification of overcurrent protection device with its clearing time
    - Enclosure dimensions and type (e.g., shallow or typical)
    - Enclosure size correction factor
    - Electrode configurations used

    - Gap between conductors (actual or default)
    - Working distance (actual or default)
    - Incident energy at working distance
    - Arc-flash boundary
    - System mode of operation if applicable
  - Documentation of the basis of calculations, such as study input data, including the source of the information (provided, calculated, typical values, etc.):
    - System modes of operation
    - Circuit breaker/relay types, manufacturer, and settings
    - Fuse sizes, types, and manufacturer
    - Equipment types (LV and MV MCCs, switchgear, switchboards, panelboards, etc.), enclosure box sizes, electrode configurations, and gap(s) between conductors
- Single-line diagram(s). The single-line diagrams may contain details on all elements within the scope of the arc-flash study as well as names/designations on the one-line diagram(s) consistent with the tabulation of study results shown in the report.
- Documentation of software used.

Additional DC data (where DC systems are within scope, 24 V to 220 Vdc):

- Nominal DC voltage, battery purpose, and battery chemistry
- Number of parallel strings and string configuration
- Prospective DC short-circuit current at the point of work (maximum credible value)
- Protection device type(s), ratings, settings (where applicable), and DC interrupting capacity
- Identification of any exposed buswork or terminations, including guarding and shrouding measures
- Task locations assessed (e.g. battery terminals, interlinks, main battery breaker, DC distribution terminations)