Sample

Arc Flash Risk Study

Using IEEE 1584-2018

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1 Introduction

1.1 Purpose

This is a sample arc flash risk study based on a fictional industrial power system. For more information about this sample report or arc flash hazard calculation studies please contact:

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1.2 Method

To determine arc hazard level the IEEE Standard 1584 can be used to calculate the incident energy and arc flash boundary. The standard provides the following method for calculation:

1. Gather data for a short-circuit and protective device coordination study
2. Calculate short-circuit current
3. Calculate the arcing current
4. Determine the trip time for the arcing current
5. Calculate the incident energy in cal/cm^2

The equations for calculating arcing current and incident energy are empirically derived from measurements performed on electrical arcs. These equations have a limited range of validity for current and voltage although for most industrial systems these limits are not reached.

1.2.1 Data Collection

Details about the electrical distribution system are required to accurately calculate the hazard level. The following lists the information typically required:

- Utility data; fault contribution and protection settings
- One Line Diagrams showing the main electrical equipment
- When one-line diagrams do not show complete distribution, an additional list should be obtained of all three-phase electrical distribution panels. These are the locations that are going to be labeled (and calculated). Loads and single-phase distribution are not applicable.
- Cable List with Sizes & Lengths. If estimated, the lengths that are at least accurate to within about 5m.
- Relay and circuit breaker setting schedule.

Typically, an onsite data collection effort is required to verify drawings are accurate. This is especially a concern for older installations.

1.2.2 Scenarios

When the electrical distribution system is operated in different modes, scenarios can be created that simulate the entire range of operating parameters. This ensures that the worst-case hazard is found. As an example, the following scenarios may be created:

- Maximum Utility – full contribution of all sources, including motors
- Minimum Utility – minimum contribution of utility and all rotating equipment out of service
- Emergency – with emergency generators supplying part of the system

A calculation needs to be performed for all applicable scenarios, evaluation should be based on the worst-case result. Which scenario yields the worst-case result is determined for each location separately.

1.2.3 *Short-circuit Evaluation*

The results of the short-circuit evaluation can be used for checking if switchgear and protective devices are adequately rated against short-circuit currents.

During data collection the short-circuit withstand of all switchgear and protective devices is gathered and compared to the maximum calculated short-circuit current. When current-limiting devices are present (such as fuses or molded-case circuit breakers) their limiting effect will be included as far as documentation is available.

The following parameters are evaluated:

- The symmetrical (RMS) withstand current for thermal withstand
- The peak current for mechanical withstand

Any issues with inadequate rating of equipment are immediately reported, as they can create unsafe working conditions.

1.2.4 *Protective Device Evaluation*

Overcurrent devices that are modelled should be checked for miscoordination for overload and short-circuit currents. When during an overcurrent more than one device trips, these devices are said to not provide full coordination, and this may present operational issues (although not necessarily safety related). In this case alternative protection settings can be explored that do provide improved or full coordination.

A report should include a list of locations where full coordination is not available. Alternative protection settings can be presented with their limits, as this is usually a compromise between operational stability, safety and cost. A setting evaluation will consider the following information:

- Connected loads and system stability
- System coordination
- Arc flash hazard levels

1.2.5 *Arc Flash Hazard Calculation*

Using the result of the short-circuit evaluation and the protection device coordination studies, the arc flash incident energy and the associated boundary can be calculated according to the equations in IEEE Standard 1584. A report should provide the calculation results, source data and any approximations or analytical variables used.

2 Study Results

2.1 Fault currents

For evaluating equipment, the results of fault calculation according to IEC 60909 are compared to withstand values of switchgear and protective devices. Equipment that is not rated high enough against short-circuit currents could fail when a fault occurs and lead to injury.

	symmetrical withstand current	IEC 60909 I''_k	assymetrical peak current	IEC 60909 I_p
swgLV	50	28	110	62
swgLV - pd-T	42	28	88	62
swgLV - pd-G	42	28	88	62
swgLV - pd-1	36	28	76	62
swgLV - pd-2	80	28	176	62
pnl1	36	13	76	22
pnl2	36	7	76	12

In this sample report no issues were found with equipment fault withstand capabilities. In case there are this typically means equipment must be replaced or protected with fault limiting protective devices such as fuses.

2.2 Coordination

A Protective Device Coordination Study is required for the arc flash hazard calculation to determine the time it takes for arc flash currents to be interrupted. The study will also show how protective devices (relays, circuit breakers and fuses) react when a fault occurs. If they are not properly coordinated, a larger part of the electrical system might be shut down to isolate a fault. The study will identify these problems and provide recommendations to improve coordination and reliability of the total electrical system.

In this sample study some issues with coordination are found for the main incoming protection breakers (pd-T and pd-G) with outgoing feeder protection pd-1:

	pd-tx	pd-T	pd-G
pd-T	full	-	-
pd-G	-	-	-
pd-1	-	9 kA	9 kA
pd-2	-	full	full

2.2.1 Solutions for improved coordination

Coordination can be improved by using settings as recommended in Table A.4.3:

	pd-tx	pd-T	pd-G
pd-T	full	-	-
pd-G	-	-	-
pd-1	-	full	full
pd-2	-	full	full

2.3 Arc Flash Hazard

With the results of the short-circuit fault and coordination study the arc flash hazard can be calculated. The IEEE 1584-2018 Guide results in a hazard calculation expressed in cal/cm² based on the arcing fault and duration.

2.3.1 *Overview of results for this sample system. For more details see annex A.6 on page 15.*

Label	Bus name / PD name (side)	Ia	t	Energy	Remarks
#001	swgLV (BUS)	18.3 kA	2.00 s	43.6 cal/cm²	Long delay for generator protection pd-G.
#001.1	swgLV / pd-G (LINE)	21.0 kA	2.00 s	22.1 cal/cm²	No protection between generator and swgLV.
#001.2	swgLV / pd-T (LINE)	18.4 kA	2.00 s	97.1 cal/cm²	Long delay for medium voltage protection pd-tx.
#002	pnl1 (BUS)	8.3 kA	0.05 s	1.0 cal/cm²	
#003	pnl2 (BUS)	4.2 kA	0.00 s	0.0 cal/cm²	

With the results of this study, control measures can be identified to reduce overall arc flash risk. As an example, in this study recommended settings have been identified that reduce hazard. This is a low-cost measure that can yield massive reduction in hazard and often improves the system coordination.

2.3.2 *Results with recommended settings with reduced arc flash risk*

Label	Bus name / PD name (side)	Ia	t	Energy	Remarks
#001	swgLV (BUS)	18.3 kA	0.10 s	6.5 cal/cm²	Shorter delay for generator protection pd-G.
#001.1	swgLV / pd-G (LINE)	21.0 kA	2.00 s	22.1 cal/cm²	No protection between generator and swgLV.
#001.2	swgLV / pd-T (LINE)	18.4 kA	0.20 s	10.1 cal/cm²	Shorter delay for medium voltage protection pd-tx.
#002	pnl1 (BUS)	8.3 kA	0.05 s	1.0 cal/cm²	
#003	pnl2 (BUS)	4.2 kA	0.00 s	0.0 cal/cm²	

2.4 Arc Flash Risk

Annex A.7 on page 17 shows an example how risk assessment for arc flash can be performed. When using this method control measures should be implemented in the following cases:

- Tasks with a *remote* or *improbable* likelihood and a calculated hazard > 1.2 cal/cm².
- Special consideration for *remote* likelihood and calculated hazard > 12 cal/cm².

Conversely, additional control measures, including PPE, are not required for:

- Tasks with a calculated hazard < 1.2 cal/cm².
- Tasks with an *incredible* likelihood.

Risk assessment is usually adapted to be in line with a company's established risk assessment method, including for example the use of a risk matrix.

3 Power System Model

The hazard calculation requires an accurate representation of the electrical system to get reliable results. Information sources are typically a combination of existing site documentation and a site visit where information is verified or completed.

3.1 Sources

- Data collection site visit
- Site electrical single line diagram (outline of electrical configuration, basic information)
- Relay and circuit breaker setting schedule (breaker types, settings)
- Cable schedule (cable sizes, lengths)

3.2 Scenarios

If PPE are used to mitigate arc flash hazard, the worst-case occurring incident energy should be considered. Because of this, the hazard calculation will consist of multiple calculations of the electrical distribution system in different switching configurations or scenarios. Some of the reasons to use multiple scenarios are emergency generators, paralleling of transformers and a difference between the minimum and maximum utility contribution.

In the sample study three scenarios are calculated, depending on the use of utility and generator contribution to faults.

Scenario	Utility	Generator
utility	yes	no
parallel	yes	yes
generator	no	yes

3.3 Assumptions & Approximations

If information is not available in the provided site documentation and these cannot be completed during a site visit, assumptions are made where they are not expected to make a large impact on arc flash hazard. In rare cases these assumptions are not possible and a range of values are used in different scenarios to make sure the worst-case is covered.

- All cable lengths are estimates rounded to the closest 5 meters.
- Thermal motor protection for motor m2 has not been modelled, as it does not affect arc flash
- Utility R/X ratio assumed at 0.1.
- Transformer X/R ratio assumed at typical values.

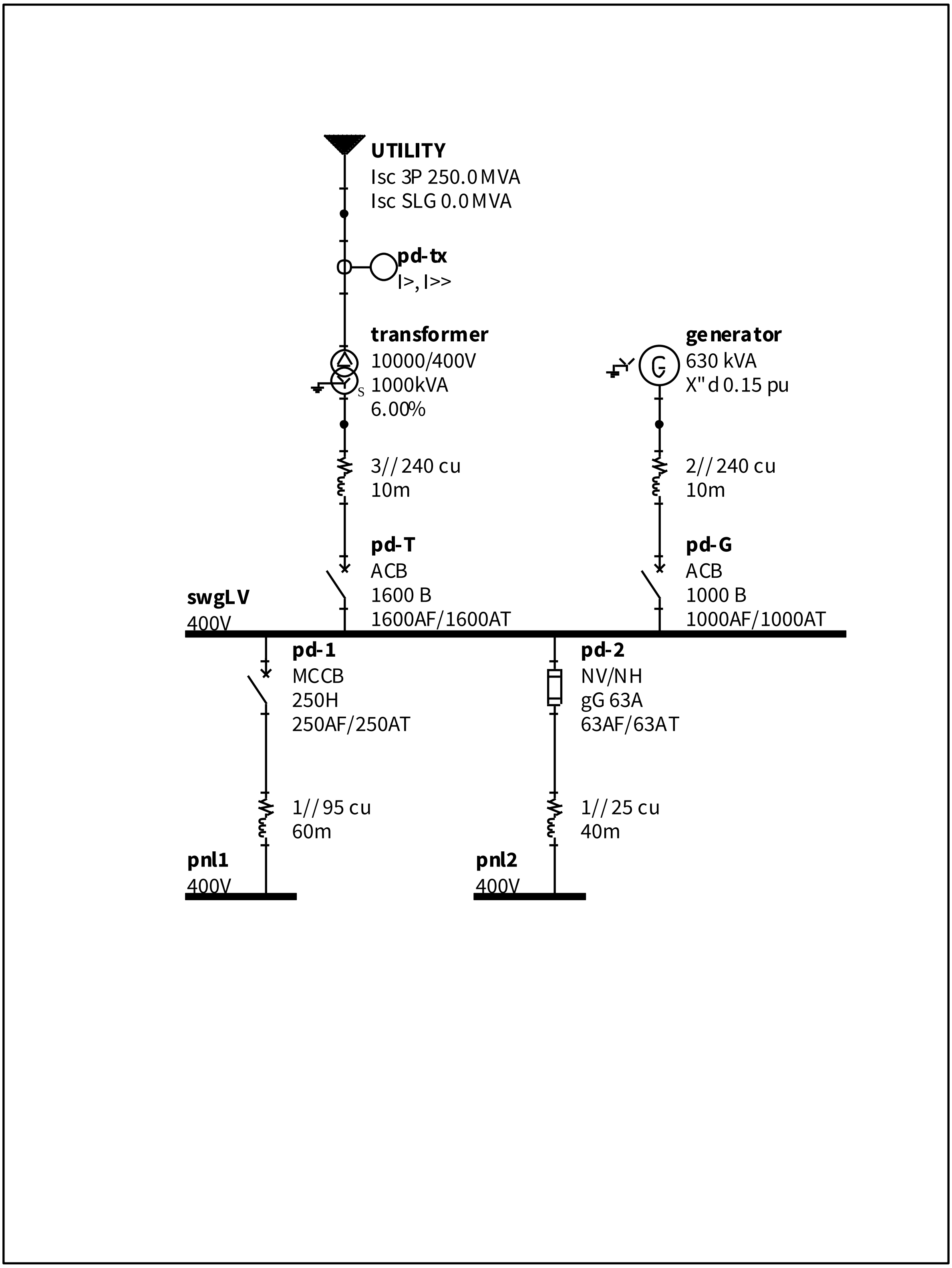
3.3.1 Maximum arcing time

The maximum arcing time has been limited to 2 seconds, based on IEEE 1584 6.9.1:

"If the time is longer than two seconds, consider how long a person is likely to remain in the location of the arc flash. It is likely that the person exposed to arc flash will move away quickly if it is physically possible and two seconds is a reasonable maximum time for calculations. A person in a bucket truck or a person who has crawled into equipment will need more time to move away."

A Calculation Results

A.1 Single Line Diagram



A.2 Input Data

A.2.1 Distribution equipment

Label #	Bus name	Voltage	Dimensions	Configuration	Withstand
#001	swgLV	400 V	508x508x250 cm	HCB	50 kA
#001.1	swgLV	400 V	750x750x250 cm	VCCB	50 kA
#001.2	swgLV	400 V	750x750x250 cm	VCCB	50 kA
#002	pnl1	400 V	508x508x250 cm	VCCB	36 kA
#003	pnl2	400 V	508x508x250 cm	VCCB	36 kA

A.2.2 Utility

Utility	Connection Service	3P Contribution SLG Contribution	Z+ (pu) Z0 pu
UTILITY	Wye-Ground In	250.0 MVA 0.0 MVA	0.0496 + j0.3969 ∞ + j∞

A.2.3 Generators

Generator	Size X''d	Voltage Ampacity	Z+ (pu) Z0 pu
Generator	630 kVA 0.15	400V 909 A	1.58 + j23.81 1.58 + j23.81

A.2.4 Transformers

Transformer	Size Vector / Z%	Voltage Ampacity	Z+ (pu) Z0 pu
Transformer	1000 kVA Dyn1 / 6.00%	10000/400V 58/1443 A	1.03 + j5.91 1.03 + j5.91

A.2.5 Cables

Cable	From To	Size Length	Z+ pu Z0 pu
c-tx	BUS-0013 swgLV	3//240 mm² cu 10.0 m	0.20 + j0.16 0.32 + j0.42
c-gen	BUS-0015 swgLV	2//240 mm² cu 10.0 m	0.30 + j0.25 0.48 + j0.62
c-pnl1	swgLV pnl1	1//95 mm² cu 60.0 m	9.23 + j3.18 14.67 + j8.09
c-pnl2	swgLV pnl2	1//25 mm² cu 40.0 m	23.18 + j2.29 36.84 + j5.81

A.3 Fault currents

A.3.1 IEC 60909 Results

Label #	Bus name	Voltage	Scenario	Ik''	Ip	Ik	Ik''(SLG)	Ip(SLG)
			utility	21.91 kA	48.68 kA	21.91 kA	22.06 kA	48.83 kA
#001	swgLV	400 V	parallel	28.25 kA	63.28 kA	22.99 kA	28.36 kA	64.14 kA
			generator	6.52 kA	15.00 kA	1.75 kA	6.48 kA	15.89 kA
			utility	11.25 kA	17.36 kA	11.25 kA	9.64 kA	14.87 kA
#002	pnl1	400 V	parallel	12.55 kA	21.84 kA	11.20 kA	10.57 kA	16.05 kA
			generator	5.39 kA	9.86 kA	1.72 kA	4.99 kA	9.24 kA
			utility	6.80 kA	9.82 kA	6.80 kA	5.78 kA	8.35 kA
#003	pnl2	400 V	parallel	7.11 kA	11.80 kA	6.82 kA	6.00 kA	8.66 kA
			generator	4.60 kA	7.08 kA	1.68 kA	4.15 kA	6.34 kA

A.3.2 Comparison of Fault Study Results with equipment ratings

	symmetrical withstand current	IEC 60909 I''_k	assymetrical peak current	IEC 60909 I_p
swgLV	50	28	110	62
swgLV - pd-T	42	28	88	62
swgLV - pd-G	42	28	88	62
swgLV - pd-1	36	28	76	62
swgLV - pd-2	80	28	176	62
pnl1	36	13	76	22
pnl2	36	7	76	12

A.3.3 Table: reference for equipment evaluation with IEC 60909 results

	symmetrical breaking current	symmetrical withstand current	asymmetrical peak current
Study Results (IEC 60909)	I''_k, I_b (1)	I_k	I_p
LV Switchgear (IEC 61439)	-	I_{CW}	I_{pk}
LV Circuit Breakers (IEC 60947)	I_{CU}, I_{CS} (2)	I_{CW}	I_{CM}
MV Switchgear (IEC 62271)	-	I_k	I_{ma}
MV Circuit Breakers (IEC 62271)	I_{SC}	I_k	I_{ma}

(1): I''k is the initial symmetrical current, with a maximum possible AC component. Ib is the breaking current at a certain time delay, which may be lower than I''k due to the AC decrement of rotating equipment.
(2): I_{CU} is the ultimate breaking capacity, I_{CS} is the service breaking capacity.

A.4 Coordination

A.4.1 Table: current protective device settings

Name	Scenario	Model Rating	Type Withstand	Settings
Relay				
pd-tx	-	75 / 5	I>, I>>	I> 1 (75A) t> 60 (sec) I>> 8 (600A) t>> 0.3 (sec)
LV Breakers				
pd-1	-	250N 250.0A/250.0A	MCCB 36 kA	Ir 250 (250A) tr Fixed Ii 6 (1500A)
pd-G	-	1000 B 1000.0A/1000.0A	ACB 42 kA	L Ir 0.9 (900A) L tr 4 S Isd 4 (3600A) S tsd 0.1 (I^s T Off) I Ii 10 (10000A)
pd-T	-	1600 B 1600.0A/1600.0A	ACB 42 kA	L Ir 0.9 (1440A) L tr 4 S Isd 4 (5760A) S tsd 0.1 (I^s T Off) I Ii 10 (16000A)
LV Fuses				
pd-2	-	gG 63A	NV/NH 80 kA	

A.4.2 Table: coordination with current settings

	pd-tx	pd-T	pd-G
pd-T	full	-	-
pd-G	-	-	-
pd-1	-	9 kA	9 kA
pd-2	-	full	full

A.4.3 Table: recommended protective device settings

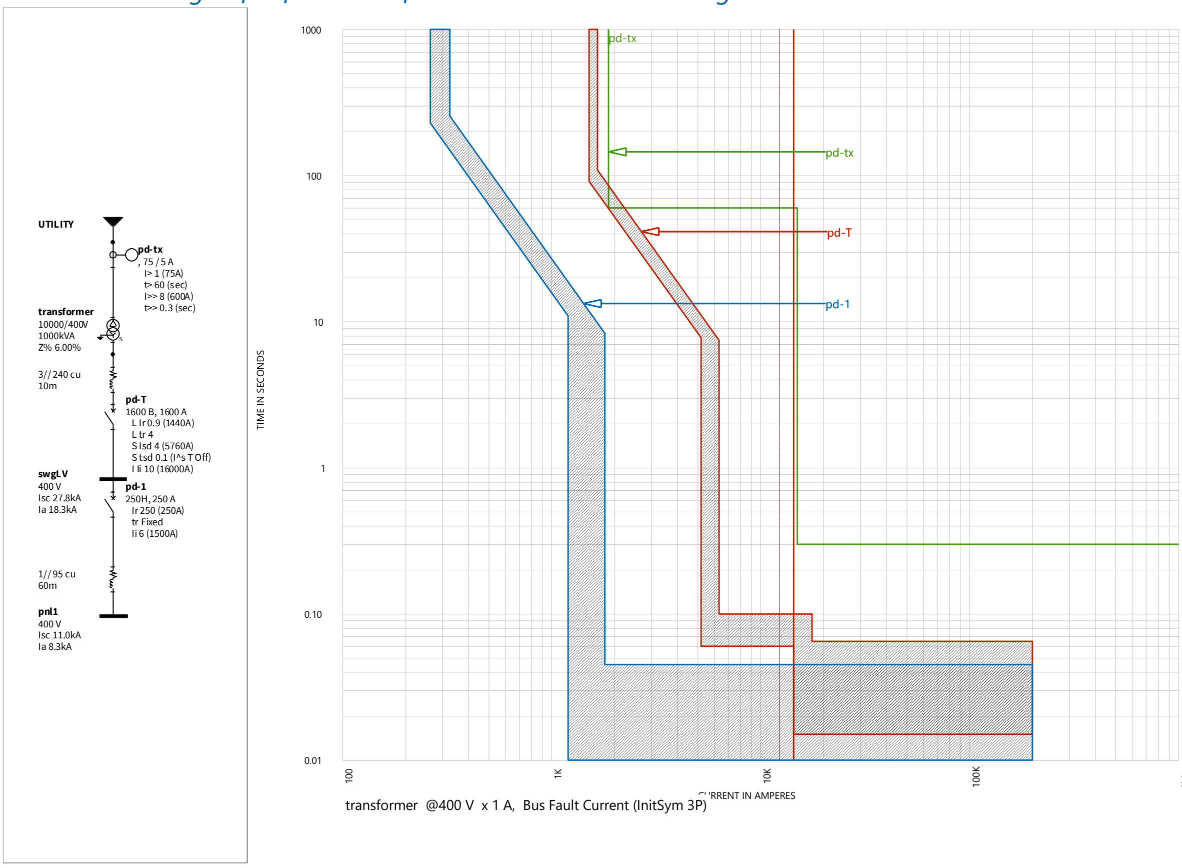
Name	Scenario	Model Rating	Type Withstand	Settings
Relay				
pd-tx	-	75 / 5	I>, I>>	I> 1 (75A) t> 60 (sec) I>> 5 (375A) t>> 0.1 (sec)
LV Breakers				
pd-1	-	250H 250.0A/250.0A	MCCB 65.0 kA	Ir 250 (250A) tr Fixed Ii 6 (1500A)
pd-G	-	1000 B 1000.0A/1000.0A	ACB 42.0 kA	L Ir 0.9 (900A) L tr 4 S Isd 3 (2700A) S tsd 0.1 (I^s T Off) I Ii 5 (5000A)
pd-T	-	1600 B 1600.0A/1600.0A	ACB 42.0 kA	L Ir 0.9 (1440A) L tr 4 S Isd 4 (5760A) S tsd 0.1 (I^s T Off) I Ii 5 (8000A)
LV Fuses				
pd-2	-	gG 63A	NV/NH 120.0 kA	

A.4.4 Table: coordination with recommended settings

	pd-tx	pd-T	pd-G
pd-T	full	-	-
pd-G	-	-	-
pd-1	-	full	full
pd-2	-	full	full

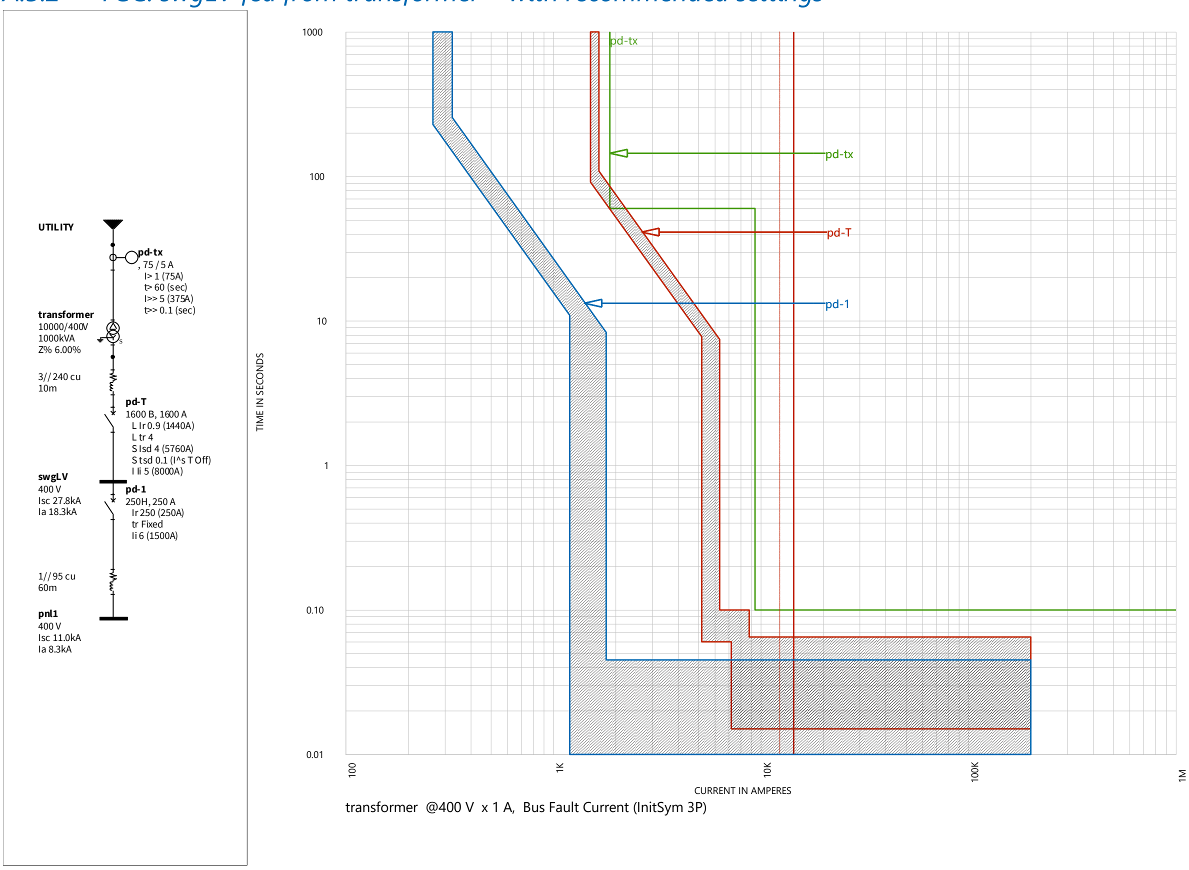
A.5 Time-current Diagrams

A.5.1 TCC: swgLV fed from transformer – with current settings



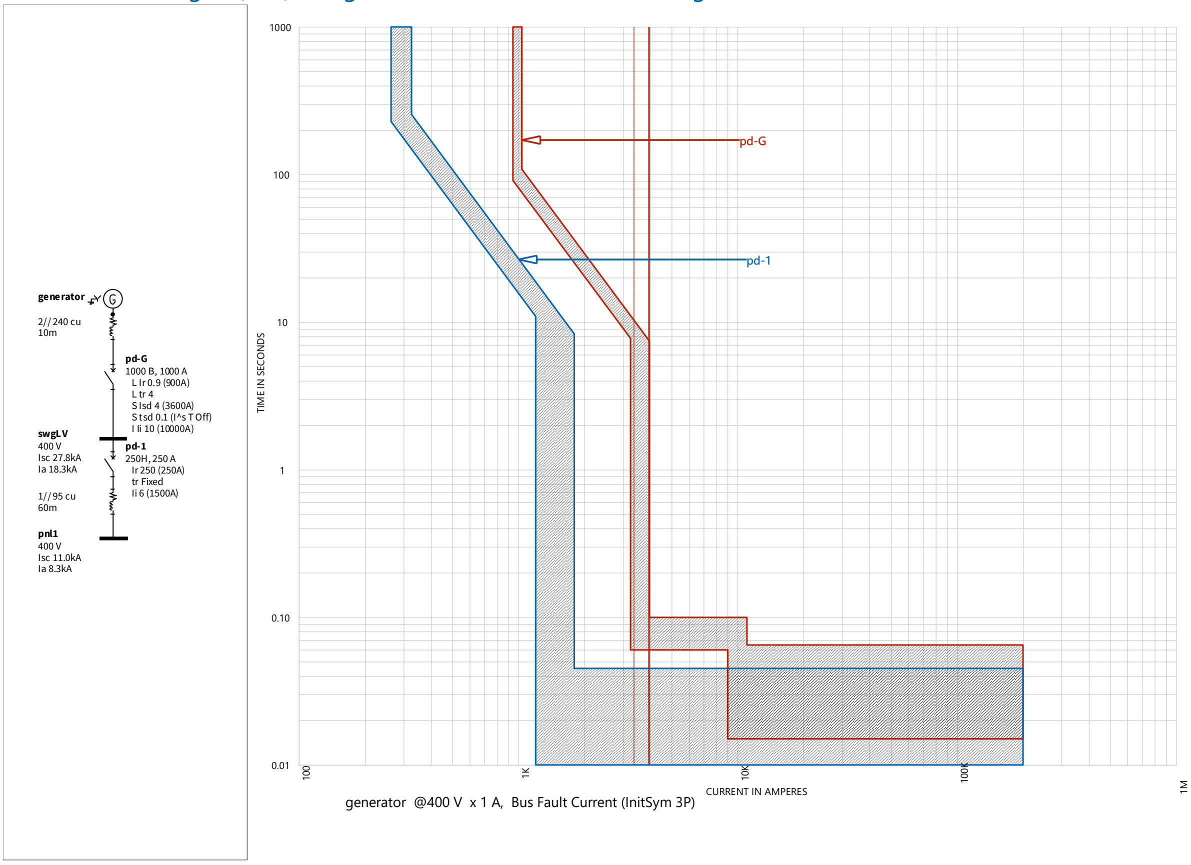
transformer @400 V x 1 A, Bus Fault Current (InitSym 3P)

A.5.2 TCC: swgLV fed from transformer – with recommended settings

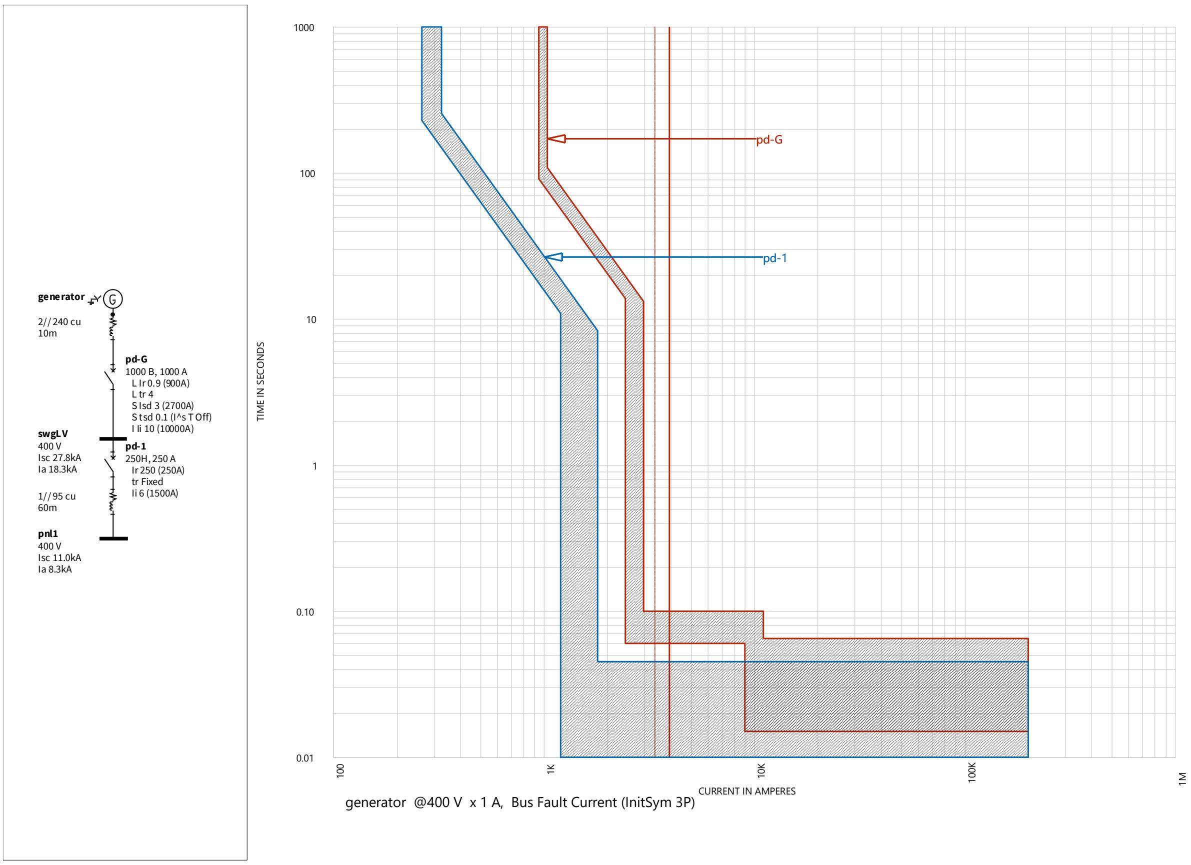


transformer @400 V x 1 A, Bus Fault Current (InitSym 3P)

A.5.3 TCC: swgLV fed from generator – with current settings



A.5.4 TCC: swgLV fed from generator – with recommended settings



A.6 IEEE 1584-2018 Calculation Results

A.6.1 Results with current settings

Label # / Scenario	Bus name / PD name (side) / Prot Dev	Volt / Isc	Gap / Ia	Config / t	Dimensions / Energy	Work D / Boundary
#001	swgLV (BUS)	400 V	25 mm	HCB	508x508x250 cm	46 cm
	pd-G	27.8 kA	18.3 kA	2.00 s	43.6 cal/cm²	2.7 m
utility	pd-T	21.9 kA	14.7 kA	0.10 s	7.2 cal/cm²	1.1 m
parallel	pd-G	27.8 kA	18.3 kA	2.00 s	43.6 cal/cm²	2.7 m
generator	pd-G	6.0 kA	3.9 kA	2.00 s	36.3 cal/cm²	2.5 m
#001.1	swgLV / pd-G (LINE)	400 V	25 mm	VCBB	750x750x250 cm	46 cm
	MaxTripTime @2.0s	27.8 kA	21.0 kA	2.00 s	22.1 cal/cm²	2.3 m
parallel	MaxTripTime @2.0s	27.8 kA	21.0 kA	2.00 s	22.1 cal/cm²	2.3 m
generator	MaxTripTime @2.0s	6.0 kA	4.4 kA	2.00 s	19.1 cal/cm²	2.1 m
#001.2	swgLV / pd-T (LINE)	400 V	25 mm	VCBB	750x750x250 cm	46 cm
	pd-tx	27.8 kA	18.4 kA	2.00 s	97.1 cal/cm²	5.2 m
utility	pd-tx	21.9 kA	14.7 kA	2.00 s	75.2 cal/cm²	4.5 m
parallel	pd-tx	27.8 kA	18.4 kA	2.00 s	97.1 cal/cm²	5.2 m
#002	pnl1 (BUS)	400 V	25 mm	VCBB	508x508x250 cm	46 cm
	pd-1	11.0 kA	8.3 kA	0.05 s	1.0 cal/cm²	0.4 m
utility	pd-1	10.1 kA	7.6 kA	0.05 s	0.9 cal/cm²	0.4 m
parallel	pd-1	11.0 kA	8.3 kA	0.05 s	1.0 cal/cm²	0.4 m
generator	pd-1	4.9 kA	3.5 kA	0.05 s	0.4 cal/cm²	0.2 m
#003	pnl2 (BUS)	400 V	25 mm	VCBB	508x508x250 cm	46 cm
	pd-2	5.7 kA	4.2 kA	0.00 s	0.0 cal/cm²	0.1 m
utility	pd-2	5.6 kA	4.0 kA	0.00 s	0.0 cal/cm²	0.1 m
parallel	pd-2	5.7 kA	4.2 kA	0.00 s	0.0 cal/cm²	0.1 m
generator	pd-2	4.0 kA	2.9 kA	0.00 s	0.0 cal/cm²	0.1 m

A.6.2 Results with recommended settings

Label # / Scenario	Bus name / PD name (side) / Prot Dev	Volt / Isc	Gap / Ia	Config / t	Dimensions / Energy	Work D / Boundary
#001	swgLV (BUS)	400 V	25 mm	HCB	508x508x250cm	46 cm
	pd-G	27.8 kA	18.3 kA	0.10 s	6.5 cal/cm²	1.1 m
utility	pd-T	21.9 kA	14.7 kA	0.07 s	4.7 cal/cm²	0.9 m
parallel	pd-G	27.8 kA	18.3 kA	0.10 s	6.5 cal/cm²	1.1 m
generator	pd-G	6.0 kA	3.9 kA	0.10 s	1.8 cal/cm²	0.6 m
#001.1	swgLV / pd-G (LINE)	400 V	25 mm	VCBB	750x750x250cm	46 cm
	MaxTripTime @2.0s	27.8 kA	21.0 kA	2.00 s	22.1 cal/cm²	2.3 m
parallel	MaxTripTime @2.0s	27.8 kA	21.0 kA	2.00 s	22.1 cal/cm²	2.3 m
generator	MaxTripTime @2.0s	6.0 kA	4.4 kA	2.00 s	19.1 cal/cm²	2.1 m
#001.2	swgLV / pd-T (LINE)	400 V	25 mm	VCBB	750x750x250cm	46 cm
	pd-tx	27.8 kA	21.0 kA	0.20 s	10.1 cal/cm²	1.5 m
utility	pd-tx	21.9 kA	16.8 kA	0.20 s	8.8 cal/cm²	1.4 m
parallel	pd-tx	27.8 kA	21.0 kA	0.20 s	10.1 cal/cm²	1.5 m
#002	pnl1 (BUS)	400 V	25 mm	VCBB	508x508x250cm	46 cm
	pd-1	11.0 kA	8.3 kA	0.05 s	1.0 cal/cm²	0.4 m
utility	pd-1	10.1 kA	7.6 kA	0.05 s	0.9 cal/cm²	0.4 m
parallel	pd-1	11.0 kA	8.3 kA	0.05 s	1.0 cal/cm²	0.4 m
generator	pd-1	4.9 kA	3.5 kA	0.05 s	0.4 cal/cm²	0.2 m
#003	pnl2 (BUS)	400 V	25 mm	VCBB	508x508x250cm	46 cm
	pd-2	5.7 kA	4.2 kA	0.00 s	0.0 cal/cm²	0.1 m
utility	pd-2	5.6 kA	4.0 kA	0.00 s	0.0 cal/cm²	0.1 m
parallel	pd-2	5.7 kA	4.2 kA	0.00 s	0.0 cal/cm²	0.1 m
generator	pd-2	4.0 kA	2.9 kA	0.00 s	0.0 cal/cm²	0.1 m

A.6.3 IEEE Std 1584 Table Header Descriptions

Header	Description
Label #	Label identification number
Bus name /PD name (side)	Location of the arc flash.
Volt	Bus voltage at the fault location (in Volts)
Gap	The spacing between bus bars or conductors at the arc location.
Config	Electrode configuration: 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
Dimensions	Dimensions of the box enclosing the arc: height, width, depth.
Work D	The working distance between the arc source and the worker's face or chest.
Scenario	Switching setup used for calculation.
Prot Dev	Protective device that interrupts the arcing current.
Isc	The current flowing to a bus fault.
Ia	The calculated arcing current [kA] on the faulted bus
t	The time [s] required for the protective device to operate for the given arcing fault condition.
Energy	The amount of energy released at the working distance.
Boundary	The distance from the arc where exposure is reduced to 1.2 cal/cm^2.

A.7 Arc Flash Risk

The goal of risk assessment is to determine when additional measures should be taken to reduce arc flash risk. Because a risk assessment method is not specified in the standards, the approach offered here is based on IEC 61508: *Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems*. Using this standard, the **frequency** and event **consequence severity** of the activity are determined that result in a risk classification. The frequency is estimated based on the task performed and the equipment condition. The consequence severity is calculated using the IEEE Standard 1584: *Guide for Performing Arc-Flash Hazard Calculations*. This risk assessment method fulfils all the requirements of NFPA 70E.

For every activity the likelihood of occurrence needs to be determined, meaning an estimate must be determined as to how often a failure leading to an arc flash may occur based on the specific activity.

A.7.1 Likelihood of occurrence

Category	Definition	Range
Frequent	Many times in system lifetime	$> 10^{-3}$
Probable	Several times in system lifetime	10^{-3} to 10^{-4}
Occasional	Once in system lifetime	10^{-4} to 10^{-5}
Remote	Unlikely in system lifetime	10^{-5} to 10^{-6}
Improbable	Very unlikely to occur	10^{-6} to 10^{-7}
Incredible	Cannot believe that it could occur	$< 10^{-7}$

A.7.2 Consequence categories.

Category	Definition
Catastrophic	Multiple loss of life
Critical	Loss of a single life
Marginal	Major injuries to one or more persons
Negligible	Minor injuries at worst

Because arc flash is a rare phenomenon, it is unlikely that any work activity performed by electrically qualified personnel would fall within the *frequent*, *probable* or *occasional* categories. The consequence of an arc flash will depend on the energy released during the event, which can range from *negligible* all the way up to *catastrophic* for extremely high energy levels.

With both the likelihood of occurrence and the consequence known, a risk class can be derived to evaluate if additional control measures are required.

A.7.3 Risk class based on likelihood of occurrence and consequence categories

	Consequence			
Likelihood	Catastrophic	Critical	Marginal	Negligible
Frequent	I	I	I	II
Probable	I	I	II	III
Occasional	I	II	III	III
Remote	II	III	III	IV
Improbable	III	III	IV	IV
Incredible	IV	IV	IV	IV

Class I: Unacceptable in any circumstance;

Class II: Undesirable: tolerable only if risk reduction is impracticable or if the costs are grossly disproportionate to the improvement gained;

Class III: Tolerable if the cost of risk reduction would exceed the improvement;

Class IV: Acceptable as it stands, though it may need to be monitored.

For arc flash incident energy, the consequence category will be divided as follows:

A.7.4 Arc flash incident energy and consequence categories

Table Error! Reference source not found..1: Arc flash incident energy and consequence categories

Incident Energy	Category	Consequence
Below 1.2 cal/cm²	Negligible	Minor injuries at worst
1.2 – 12 cal/cm²	Critical	Loss of a single life
Over 12 cal/cm²	Catastrophic	Multiple loss of life

The likelihood of occurrence for electrical arcs depends on the task performed and the condition of the equipment. The table below is based on NFPA 70E table 130.5(C), but adjusted to only show the likelihood, not risk assessment results.

A.7.5 Likelihood of occurrence for tasks with possible exposure to electrical arcs.

Task	Likelihood
Reading a panel meter while operating a meter switch.	Incredible
Examination of insulated cable with no manipulation of cable.	Incredible
Operation of a CB, switch, contactor, or starter. Normal equipment condition.	Incredible
Removal or installation of covers for equipment such as wireways, junction boxes, and cable trays that does not expose bare, energized electrical conductors and circuit parts. Normal equipment condition.	Incredible
Opening a panelboard hinged door or cover to access dead front overcurrent devices. Normal equipment condition.	Incredible
Performing infrared thermography and other non-contact inspections outside the restricted approach boundary. This activity does not include opening of doors or covers.	Improbable
Working on control circuits with exposed energized electrical conductors and circuit parts, nominal 125 volts ac or dc, or below without any other exposed energized equipment over nominal 125 volts ac or dc, including opening of hinged covers to gain access.	Improbable
For dc systems, insertion or removal of individual cells or multi-cell units of a battery system in an open rack.	Improbable
For dc systems, maintenance on a single cell of a battery system or multi-cell units in an open rack.	Improbable
Removal of battery nonconductive intercell connector covers. Normal equipment condition.	Improbable
Voltage testing on individual battery cells or individual multi-cell units. Normal equipment condition.	Improbable
For ac systems, work on energized electrical conductors and circuit parts, including voltage testing.	Remote
For dc systems, working on energized electrical conductors and circuit parts of series-connected battery cells, including voltage testing.	Remote
Removal or installation of CBs or switches.	Remote
Opening hinged door(s) or cover(s) or removal of bolted covers (to expose bare, energized electrical conductors and circuit parts). For dc systems, this includes bolted covers, such as battery terminal covers.	Remote
Application of temporary protective grounding equipment, after voltage test.	Remote
Working on control circuits with exposed energized electrical conductors and circuit parts, greater than 120 volts.	Remote
Insertion or removal of individual starter buckets from motor control center (MCC).	Remote
Insertion or removal (racking) of circuit breakers (CBs) or starters from cubicles, doors open or closed.	Remote
Examination of insulated cable with manipulation of cable.	Remote
Working on exposed energized electrical conductors and circuit parts of equipment directly supplied by a panelboard or motor control center.	Remote
Insertion or removal of revenue meters (kW-hour, at primary voltage and current).	Remote
Removal of battery conductive intercell connector covers.	Remote
Opening voltage transformer or control power transformer compartments.	Remote
Operation of outdoor disconnect switch (hookstick operated) at 1 kV through 15 kV.	Remote
Operation of outdoor disconnect switch (gang-operated, from grade) at 1 kV through 15 kV.	Remote
Maintenance and testing on individual battery cells or individual multi-cell units in an open rack. Abnormal equipment condition.	Remote
Insertion or removal of individual cells or multi-cell units of a battery system in an open rack. Abnormal equipment condition.	Remote
Arc-resistant switchgear Type 1 or 2 (for clearing times of less than 0.5 sec with a prospective fault current not to exceed the arc-resistant rating of the equipment) and metal enclosed interrupter switchgear, fused or unfused of arc resistant type construction, 1 kV through 15 kV. Abnormal equipment condition.	Remote
Insertion or removal (racking) of CBs from cubicles; Insertion or removal (racking) of ground and test device; or Insertion or removal (racking) of voltage transformers on or off the bus. Abnormal equipment condition.	Remote

Normal equipment condition is defined as:

- The equipment is properly installed in accordance with the manufacturer's recommendations and applicable industry codes and standards.
- The equipment is properly maintained in accordance with the manufacturer's recommendations and applicable industry codes and standards.
- The equipment is used in accordance with instructions included in the listing and labeling and in accordance with manufacturer's instructions.
- Equipment doors are closed and secured.
- Equipment covers are in place and secured.
- There is no evidence of impending failure such as arcing, overheating, loose or bound equipment parts, visible damage, or deterioration.

Using the tables above we obtain the following risk classes for electrical arcs:

A.7.6 *Risk class for electrical arcs*

Hazard	Likelihood	Consequence	Risk Class
	Remote	Catastrophic	Class II
Over 12 cal/cm²	Improbable	Catastrophic	Class III
	Incredible	Catastrophic	Class IV
	Remote	Critical	Class III
1,2-12 cal/cm²	Improbable	Critical	Class III
	Incredible	Critical	Class IV
	Remote	Negligible	Class IV
Under 1,2 cal/cm²	Improbable	Negligible	Class IV
	Incredible	Negligible	Class IV

These results show that control measures should be implemented in the following cases:

- Tasks with a *remote* or *improbable* likelihood and a calculated hazard > 1.2 cal/cm².
- Special consideration for *remote* likelihood and calculated hazard > 12 cal/cm².

Conversely, additional control measures, including PPE, are not required for:

- Tasks with a calculated hazard < 1.2 cal/cm².
- Tasks with an *incredible* likelihood.