Eskom	**Standard**	**Asset Management**

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CONTENTS

TABLES

1. INTRODUCTION

Metal enclosed switchgear are operated and maintained in all Generation power stations in Eskom. Metal enclosed switchgear consists of Low and Medium voltages. The metal enclosed switchgear installed at power stations presents risk to operating and maintenance staff and needs special precaution to evaluate the risk associated with thermal hazards of an electric arc. The level of risk varies between switchgear that is internal arc compliant and non-internal arc compliant.

The majority of the metal enclosed switchgear that are non-internal arc compliant were installed prior to the introduction of the latest international standards for internal arc classification of switchboards, and hence pose a safety risk. Metal enclosed switchgear that are internal arc compliant according to the latest international standards for safety, may still pose minor safety risks that shall be considered.

This Standard provides direction to users of the metal enclosed switchgear by referencing various local and international standards and guidelines to quantify the level of protection against thermal hazards of an electric arc required during operating and maintenance activities.

This standard shall be used in conjunction with 240-70044736 - Arc Flash Protective Clothing and Personal Protective Equipment against the Thermal Hazard of an Electrical Arc Specification **[3]**.

2. SUPPORTING CLAUSES

2.1 SCOPE

2.1.1 Purpose

The purpose of this standard is to set out the minimum requirements to be adhered to by Generation employees and contractors during the operation and maintenance of metal enclosed switchgear which are internal arc and non-internal arc compliant.

This standard also covers the selection requirements of arc flash protective clothing and personal protective equipment against the thermal hazard of an electrical arc. The selection of such arc flash protective clothing and personal protective equipment shall be required for access and/or working in close proximity to metal enclosed switchgear.

2.1.2 Applicability

This document shall apply in Eskom Generation Division.

2.2 NORMATIVE/INFORMATIVE REFERENCES

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] ISO 9001 Quality Management Systems.
[2] OHS Act Occupational Health and Safety Act and Regulations (85 of 1993).
[3] 240-70044736 Arc Flash Protective Clothing and Personal Protective Equipment against the Thermal Hazard of an Electrical Arc Specification.
[4] 240-114967625 Operating Regulations for High Voltage Systems.

[5] 240-150642762 Generation Plant Safety Regulations.

[6] IEEE 1584 (SANS 984) IEEE Guide for performing arc flash hazard calculation.

[7] SANS 724 Personal Protective Equipment and Protective Clothing against the Thermal Hazards of an Electric Arc.

[8] NFPA 70E Standard for Electrical Safety in the Work Place.

[9] 240-103162618 Report on Retrofit Solutions For Underrated and/or Non Internal Arc Classified Switchgear.

[10] Cigre WG B3.37 Mitigating the Effects of Arcs in MV Switchgear.

[11] IEEE Press Power Engineering Arc Flash Hazard Analysis and Mitigation - J.C. Das.

[12] Arc Flash Calculations for Exposures to DC System, IEEE transactions on Industrial Applications, Vol 46, No. 6, 2010 - D.R Doan.

[13] 240-56227573 AC Metal Enclosed Switchgear and Control gear for Voltages above 1 kV up to and including 52kV.

[14] 240-56227516 LV Switchgear Control gear Assembly Associated Equipment for Voltage 1000V AC and 1500V.

[15] 240-82332407 Generation Fixed Pattern Gas Insulated Metal-Enclosed Indoor Primary Switchgear and Control gear Specification for Rated Voltages above 1kV up to and including 52kV

[16] 240-56030406 Ring main units for systems with nominal voltages from 3.3 kV to 33 kV.

[17] 240-56062757 Specification for medium voltage miniature substations for systems with nominal voltages of 3.3 kV, 6.6 kV, 11 kV and 22 kV standards.

[18] 240-56997043 Maintenance Standards for MV Indoor Primary Switchgear.

2.2.2 Informative

[19] 240-56535985 Operations Management of Medium Voltage Switchgear used in Eskom Power Stations Work Instruction.

2.3 DEFINITIONS

The definitions of SANS 984 (IEEE 1584), NFPA70E and this document shall apply.

Definition	Description
Approved by	The accountability of the Approver of the document is equivalent to the specified role of Functional Responsible/Owner as identified in 240-53114186 and 32-6 for Documents and Records Management.
Arc Flash Boundary	When an arc flash hazard exist, an approach limit at a distance from a prospective arc source within which a person could receive a second degree burn if an electrical arc flash were to occur. Note: a second degree burn is possible by an exposure of unprotected skin to an electric arc flash above the incident energy level of 5 J/cm^2 (1.2 cal/cm^2).
Arc Flash Hazard	A dangerous condition associated with the possible release of energy caused by an electrical arc.
Arc Rating	The value attributed to material that describes their performance to exposure to an electrical arc discharge. The arc rating is expressed in cal/cm^2 or J/cm^2 and derived from the determined value of the arc thermal performance (ATPV), energy break-open threshold (E_{BT}) or Incident Energy Limit Value

Definition	Description
	(ELIM).
Arc Thermal Performance Value	In arc testing, this means the incident energy on a material or multilayer system of materials that results in a 50% probability that sufficient heat transfer through the tested specimen is predicted to cause the onset of a second-degree skin burn injury based on the Stoll curve, without breaking open. **NOTE**: ATPV is expressed in kJ/m^2 or $kW \times s/m^2$ (cal/cm^2).
Arc-rated Face Shield	Face shield designed to protect a person from electrical blast/flash with a minimum ATPV rating of 33.4 $Joule/cm^2$ (8 cal/cm^2) worn in combination with a hard hat.
Close proximity	Any public or Eskom appointed personnel accessible location that is within the calculated and or defined arc flash protection boundary of the metal enclosed switchgear.
Incident Energy	The amount of energy impressed on a surface, a certain distance from the source generated during an electrical arc event. It is measured in J/cm^2 or cal/cm^2.
Incident Energy Analysis	A component of an arc flash risk assessment used to predict the incident energy of an arc flash for a specified set of conditions.
Internal arc proof/classified metal enclosed switchgear	Metal enclosed switchgear tested and compliant in accordance with SANS 62271-200 and SANS 62271-202 for MV switchgear, and SANS 61641 for LV switchgear. **NOTE**: Arc resistant sometimes is used interchangeably with the above terms.
Metal enclosed switchgear	MV and LV switchgear in accordance with the relevant SANS /IEC equipment specification standard, that are defined as metal enclosed switchgear or are installed in metal enclosures. i.e. MV indoor primary switchgear of the withdrawable or fixed pattern type, free standing MV ring main units, MV RMUs mounted in Miniature substations, LV switchgear panels (e.g. Miniature substation LV compartments, Distribution boards, etc.).
Non-Arc flash PPE	This refers to minimum generic Eskom PPE (240-44175132) includes flame retardant overalls / pants and shirt, and safety shoes/boots.
PPE Category 2 and 2a	In the context of reasonable safety practices in Eskom, PPE Category 2 is broken down into 2 and 2a. Where PPE Category 2 is body, eyes, head and hearing protection such as arc rated long pants and jacket or arc rated coverall and hard hat as well leather footwear. PPE Category 2a is body, eyes, head, hearing, hands and face protection as well as leather footwear.
Protective Clothing and Personal Protective Equipment	All items including head, face, neck and chin protection, eye protection, hearing protection, body protection, hand and arm protection, foot and leg protection intended to protect a person against the thermal hazards of an electric arc.
Working Distance	The sum of the distance between the Worker standing in front of the equipment, and from the front of the equipment to the potential arc source inside the equipment.

2.3.1 Disclosure Classification

Controlled Disclosure: Controlled Disclosure to external parties (either enforced by law, or discretionary).

2.4 ABBREVIATIONS

Abbreviation	Description
ATPV	Arc Thermal Performance Value
IAC	Internal Arc Classified
LV	Low Voltage
MV	Medium Voltage
PD	Partial Discharge
PPE	Personal Protective Equipment

2.5 ROLES AND RESPONSIBILITIES

General Managers

- The General Manager is responsible to ensure that a person responsible for electrical safety is appointed. (OHS Act no 85 of 1993 section 8).
- General Manager is responsible for peer reviews to evaluate the implementation of the standard and internal safety reviews.

GMR2(1)

- GMR2(1) appointees, throughout Eskom holdings shall ensure safety of personnel by ensuring that this standard is utilised when conducting electrical work where there is a possibility of arc flash hazard.
- Maintain compliance for the use Arc flash PPE.

Operating and Maintenance Manager

- Ensures that Metal Enclosed Switchgear is operated and maintained in accordance with the minimum requirements provided in this standard.
- Ensure that Arc Flash PPE is used at all times according to the rules.
- Ensure that the operating and maintenance personnel is trained and authorised to perform his/her duties to meet the requirements of this standard and associated policy. Review training material to be in line with the Generation Policy and Standard.

Switchgear System Engineer

- Ensures that incident energy and arc flash boundaries calculations for all switchboards are performed.
- Ensures that arc flash PPE complies with the arc flash PPE standard **[3]**.

2.6 PROCESS FOR MONITORING

Operating and Maintenance weekly sessions and meetings as per **Eleven Point Plan.**

2.7 RELATED/SUPPORTING DOCUMENTS

- All Normative referenced documents.
- Eleven point safety plan for non-Internal arc proof/classified metal enclosed switchgear.

3. REQUIREMENTS

3.1 BACKROUND

The most common reasons for arc flash accidents are due to human error, mechanical faults, failed connections, insulation deterioration, adverse ambient conditions and pollution and also rodents. Statistics of arc flash incidents indicates that 65% of accidents occur when the operator or worker is working with equipment doors open while 10% of accidents occur when the operator happens to be in front of a closed door and the equipment is not arc resistant and 25% happens when the operator is not present at all and the equipment is not arc resistant **[11]**.

The IEEE Guide equations are based upon the hazard calculations with the door open **[11]**. With the door closed, the hazard level will be less, though it is not easy to calculate it. The manufacturers are reinforcing the latching mechanisms and strengthening the doors which improve the withstand capability of the doors in a closed position under an arc flash event. However, the improvement can ONLY be proven through type testing of equipment for internal arc withstand (arc resistant).

It is for the above reasons that when calculating incident energy for internal arc proof/classified metal enclosed switchgear, the corresponding arc flash PPE requirements may not necessarily be as stringent as for non-internal arc proof/classified metal enclosed switchgear.

3.2 INTERNAL ARC EFFECTS (IDENTIFIED RISKS)

a) Gas flow as the main phenomenon during arcing, resulting in extremely hot and toxic gasses that need to be vented out of the faulty compartment of the metal enclosed switchgear.

b) Sound waves generated by the sudden expansion of the plasma volume of the arc.

c) The radiated light from the arc.

d) Pressure rise, pressure wave and pressure release as a function of the arc duration in the faulty compartment and metal enclosed switchgear room where applicable.

e) Arc burn through steel enclosure walls.

f) Material vaporization and burning of materials due to the arc (i.e. hot/burning oil splashing during arcing).

g) Pollution of the metal enclosed switchgear in the faulty compartment, adjacent compartments and room due to the gas flow pollutants.

h) Switchgear room overpressure, contamination, toxicity exposure, and thermal damage.

3.3 GENERAL SAFETY WORK GUIDELINES

The following safety work guidelines shall be adhered to in conjunction with the Eleven Point Safety Plan found in **Appendix A**.

a) When a circuit has been de-energized by a short circuit protective device (e.g. circuit breaker or fuse) this event must be investigated according to the local procedure prior to re-energising. The authorised person shall sanction the re-energising of the plant which has tripped on protection.

- Do not manually re-energise the circuit without first investigating the cause.
- Do not perform repetitive manual re-energising.

b) Prior to working in close proximity to an exposed energised source, workers must remove all jewellery and metallic objects. (e.g. rings, watches, chains and keys) in order to prevent electric shock and the onset of an electrical arc:

- Jean zippers and studs are not a concern unless the body position will place the worker in a position where the item may come in contact with an exposed energised source,
- Remove lanyards to prevent the metal ring/clip from contacting an exposed energised source,
- Remove metal framed glasses or restrain them.

c) When covers, doors or guards are removed from energised equipment, if left unattended, it shall be barricaded.

d) Ensure that the eleven point safety plan is adhered to. (See **Appendix A**)

e) When doing maintenance and/or operating in remote locations outside the normal response time of the fire and rescue team, the authorised person must ensure that appropriate rescue equipment e.g. rescue hook and defibrillator are on job prior to working.

f) Adhere the Eskom Life Saving rule to Isolate, Test and Earth before touch - Consider all plant live until performing the test for dead.

g) The person doing fault finding must be skilled, authorised, have sufficient knowledge pertaining to the electrical system being worked on and know the maximum voltage to be expected in the panel.

h) Use the appropriate measurement and test equipment, adequately rated for the current and voltage levels to be measured.

i) Ensure that such equipment is used in the correct measurement scale for the electrical parameter to be measured. Test equipment shall have valid calibration certificate.

j) Use insulated probes and tools to ensure that short circuits cannot be caused when live parts are accidentally touched.

k) At voltage levels exceeding 1000V, conventional test and measurement equipment (e.g. line tester or multimeter) cannot be used.

l) Nobody is allowed on top of any switchgear panels that are energized.

m) Access into the control and protection LV compartment while primary circuit is energised is allowed on MV metal enclosed switchgear if MV switchgear is metal partitioned and type tested for LV compartment access. If the MV switchgear is not type tested for LV compartment access, necessary precautions and risk assessment (consider adequate face and body protection) shall be undertaken before access is granted.

n) All MV metal enclosed switchgear operation that includes: circuit breakers, contactors, switch disconnectors, racking and earthing shall be performed remotely via the use of umbilical cords, local control panels, robotic (free standing) type operating arms or devices or remote control IEDs as far as reasonably possible.

o) Ensure to comply with internal arc proof/classification type testing requirements, and all safety measures to prevent exposure to internal arc effects. e.g. avoid rear access of the MV switchgear if the arc vents are located at the back.

p) Frequent measuring and recording of Partial Discharge (PD) should be performed in order to monitor the deterioration of PD.

3.4 SKILLS, TRAINING AND AUTHORISATION

a) It is to be understood that specific skills are required for the specific roles and responsibilities before any operation and / or maintenance of MV and LV metal enclosed switchgear can be done.

b) It is required that any operating and / or maintenance on MV and LV metal enclosed switchgear shall be done by personnel that are suitably trained and authorised for the task expected of them, on MV and LV metal enclosed switchgear that are considered safe to do so.

c) Due to the complexities of electrical power system configurations and equipment, incident energy and arc flash boundary calculations shall be performed by competent engineering personnel.

d) When conditions concerning the application of protective clothing and protective equipment change, station staff exposed to possible electrical arc flash hazards needs to be re-trained and re-authorized.

3.5 RECORD KEEPING

Record keeping is important in terms of training and authorisation on the correct use and maintenance of issued protective clothing and protective equipment. All records shall be kept and filed appropriately.

3.6 INCIDENT ENERGY AND ARC FLASH BOUNDARY

3.6.1 Calculations for Incident Energy and Arc Flash Boundary

There are formulae available to calculate the incident energy and the arc flash boundary, however, these formulae are empirically derived (i.e. they were developed through statistical analysis of test data) and have limitations. See formulae contained in the IEEE1584 (SANS 984) guideline **[6]** and IEEE paper authored by D.R. Doan **[12]**.

3.6.2 Limitations on formulae

a) IEEE 1584 (SANS 984) guideline provide calculations for incident energy and arc flash boundary for: 208V to 15kV; three phase system, 700A to 106kA short circuit current; and 13mm to 152mm conductor gaps. The formulae may not be used for DC and single phase systems and do not cover 22kV and 33kV applications. IEEE 1584 (SANS 984) covers an empirically derived model for voltages from 208V to 15 kV, and a theoretically derived model applicable for any voltage.

b) For DC systems calculations for incidents energy on DC system rated up to 1000 kV, there is an adopted IEEE paper by D.R Doan, "Arc Flash Calculations for Exposures to DC System", *IEEE transactions on Industrial Applications, Vol 46, No. 6, 2010*. This IEEE paper is attached on **Appendix B**.

3.7 ARC FLASH PPE SELECTION

PPE worn for the protection from arc flash hazard is considered last line of defence. The PPE is not intended to prevent all injuries but to reduce the impact of an arc flash upon the individual, should one occur. In many cases, the use of arc flash PPE has saved lives and/or prevented injury. The calculation of incident energy and the arc flash boundary from the guide IEEE 1584 (SANS 984) enable PPE selection that provides a balance between the calculated incident energy exposure and work activity being performed while addressing the following concerns:

a) The desire to provide enough protection to prevent a second degree burn in all cases.

b) The desire to avoid providing more protection than is needed. Hazards may be introduced by the garments such as heat stress, poor visibility, and limited body movement.

Arc flash PPE shall be worn by all personnel within the arc flash boundary. There are two methods used for selection of arc flash PPE:

a) Incident energy analysis method.

b) Arc flash PPE category method.

3.7.1 Incident Energy Analysis Method

a) The incident energy exposure level shall be based on the working distance of the employee's face and chest areas from a prospective arc source for the specific task to be performed. Arc-rated clothing and other PPE shall be used by the employee based on the incident energy exposure associated with the specific task. Recognizing that incident energy increases as the distance from the arc flash decreases, additional PPE shall be used for any parts of the body that are closer than the working distance at which the incident energy was determined.

b) Incident energy and arc flash boundaries of each Switchboard shall be calculated using formulae found in SANS 984(IEEE 1584) guideline.

c) Due to the complexities of electrical power system configurations and equipment, incident energy and arc flash boundary calculations shall be performed by competent engineering practitioner.

d) Once the incident energy value in known, the arc rated PPE may be chosen. In practice, arc rating of the PPE is always equal to or greater than the estimated incident energy.

e) Risk Assessment is conducted to estimate the likelihood of occurrence of an arc flash event to determine if additional protective measures are required. When conducting a Risk Assessment, severity of the task, equipment conditions and switchgear type test status are evaluated.

3.7.2 Arc Flash PPE Category Method

a) This method is used for selection of arc flash PPE based on estimated incident energies obtained for different classes of switchgear. These incident energies are as a result of estimated maximum available fault current, maximum fault clearing times, operating voltages, clearance distance between busbars and minimum working distances for various types of switchgear.

b) Table 130.7(C)(15)(a) and (b) in NFPA 70E 2018 provide list of different switchgear (AC and DC) classes and their corresponding required arc flash PPE category and arc flash boundary.

c) When the Switchgear type is identified in Table 130.7(C)(15)(a) and (b), the PPE items of the corresponding Arc flash PPE category are selected in Table 130.7(C)(15)(c).

d) Similar to Incident Energy Analysis method of determining arc flash PPE, Risk Assessment is conducted to estimate the likelihood of occurrence of an arc flash event to determine if additional protective measures are required. When conducting a Risk Assessment, severity of the task, equipment conditions and switchgear type test status are evaluated.

3.8 ESKOM RECOMMENDED ARC FLASH PPE SELECTION

The recommended method for Generation power stations is to adopt a hybrid method for the selection of PPE by using both incident energy analysis and arc flash PPE category methods. It must be understood that it will almost be reasonably impractical for the power station to manage and implement all four PPE Categories items or to have multiple arc flash PPE ratings for all varying Incident Energies. As a result, only two arc flash PPE categories shall be used, namely; arc flash PPE Category 2 (2a) and 4 with minimum arc rating of 12cal/cm^2 and 50cal/cm^2 respectively as shown in **Table 1**. It is noted that some power stations are using 40cal/cm^2 currently, therefore going forward, for new orders of Arc flash PPE from the market, 50cal/cm^2 shall be ordered. In otherwords, 40cal/cm^2 arc flash PPE in service shall be used until the end of its service life. This will also apply to arc flash PPE in stock (Stores) which will be dispatched to users.

a) Incident energy and arc flash boundary for each MV and LV Switchgear shall be calculated. For switchgear inside the switchgear room, the arc flash boundary shall be at the door of the room. Incident energies shall be calculated on the main busbars and using short circuit protection devices (SCPD) of the incomer of the switchboards/boards.

b) **Table 4** and **Table 5** provide guidance to the safety requirements in relations to certain activities.

Table 1: Selection of Arc rated clothing and other PPE.

Arc Flash PPE Category	PPE Arc Rating	PPE Items
2a	Minimum 12 cal/cm^2	Arc-rated Long sleeve shirt and pants or coverall
		Arc-rated face shield and arc-rated balaclava
		Heavy duty leather gloves, arc-rated gloves or rubber insulating gloves with leather protection
		Hard hat
		Safety glasses or safety goggles
		Hearing protection
		Leather footwear
2	Minimum 12 cal/cm^2	Arc-rated Long sleeve shirt and pants or coverall
		Safety glasses or safety goggles
		Hard hat
		Hearing protection
		Leather footwear
4	Minimum 50 cal/cm^2	Arc-rated Long sleeve shirt and pants or coverall or arc flash suit
		Arc-rated arc flash suit hood
		Heavy duty leather gloves, arc-rated gloves or rubber insulating gloves with leather protection
		Hard hat
		Safety glasses or safety goggles
		Hearing protection
		Leather footwear

3.9 DEMARCATION OF ARC FLASH PROTECTION BOUNDARY

a) Arc flash boundaries shall be calculated for each switchgear room, however, for all persons entering a switchgear room for any maintenance, repair, testing, fault finding or operating (this is also applicable to the accompanying personnel) the demarcation line of flash protection boundary is the access door to a switching room.

b) In case where switchgear is installed in open space (No access door exists), then the following distance are the minimum safety zones as specified below.

Table 2: Typical arc flash boundary protection.

FLASH PROTECTION BOUNDARY	
VOLTAGE (VOLTS)	**DISTANCE (METERS)**
50 to 750	0.9
750 to 1,000	1.2
1,000 to 11,000	4.8

Note: Verification of flash boundary specified in this table has to be verified in later stage by calculation. A simple tool (base on IEEE 1584 guide) that can be used for the calculations required is the “Arc Flash Analytic” which will provide a reasonably accurate calculation.

c) When boundaries are required to support maintenance, repair, testing, fault finding or operating on/near energised equipment, alert others in the vicinity of the potential arc flash hazards associated with the work/operating.

d) The flash protection boundary shall be maintained when maintaining, repairing, testing, fault finding or operating around energised equipment.

3.10 DETERMINING OF WORKING DISTANCE

Working Distance is defined as the sum of the distance between the worker standing in front of the equipment, and from the front of the equipment to the potential arc source inside the equipment. IEEE1584 (SANS 984) guideline provide typical Working Distances for different Switchgear voltage ratings illustrated in Table 3. However, it is highly recommended that Working Distances be determined on each Switchgear type as this could reduce the resultant Incident Energy, especially when the distance is longer than typical distances in below table.

Table 3: Typical Working Distances for MV and LV Switchgear.

Switchgear	Typical Working Distance (mm)
MV Switchgear (above 1000V up to and including 15kV)	910
LV Switchgear (above 200V up to 1000V)	455

3.11 REQUIREMENTS FOR ACCESS AND WORK IN CLOSE PROXIMITY TO MV AND LV SWITCHGEAR

The **Table 4** and **Table 5** below provide different types of MV and LV switchgear with related activities and the corresponding recommended safety requirements.

Table 4: Requirements for access and work in close proximity to MV switchgear.

ACTIVITY TYPE / SWITCHGEAR TYPE	ACCESS (GOING INSIDE THE SWTCHGEAR ROOM), VISUAL INSPECTION AND LV COMPARTMENT WORK	LOCAL OPERATING	SCHEDULED/ BREAKDOWN MAINTENANCE	CABLE TERMINATION: BREAKDOWN OR NEW INSTALLATION
Internal Arc Classified (IAC) Primary Indoor MV Switchgear	PPE Category 2 – as shown in Table 1. **Note**: the need for face and hand protection shall be evaluated based on the activity.	1) Use stand-off operating device and standard non-Arc Flash PPE or 2) PPE Category 2a – as shown in Table 1.	De-energise switchgear busbar section to be worked on, and standard non-Arc Flash PPE.	1) De-energise switchboard section & standard non-Arc Flash PPE, or 2) De-energise panel to be worked on, immediate adjacent panels, and PPE Category 2 – as shown in Table 1.
Non- Internal Arc Classified Primary Indoor MV Switchgear	PPE Category 2 – as shown in Table 1. **Note**: the need for face and hand protection shall be evaluated based on the activity.	1) Use stand-off operating device and standard non-Arc Flash PPE, or 2) PPE Category 4 – as shown in Table1.	De-energise switchgear busbar section to be worked on, and standard non-Arc Flash PPE.	1) De-energise switchboard section & standard non-Arc Flash PPE, or 2) De-energise panel to be worked on, immediate adjacent panels, and PPE Category 2 – as shown in Table 1.
Internal Arc Classified (IAC) Ring Main Unit (RMU)	PPE Category 2 – as shown in Table 1. **Note**: the need for face and hand protection shall be evaluated based on the activity.	PPE Category 2a – as shown in Table 1.	De-energise switchgear busbar section to be worked on, and standard non-Arc Flash PPE.	1) De-energise entire RMU& standard non-Arc Flash PPE, or 2) De-energise panel to be worked on, immediate adjacent panels, and PPE Category 4 – as shown in Table 1.

Non-Internal Arc Classified Ring Main Unit (RMU)	PPE Category 2 – as shown in Table 1. **Note**: the need for face and hand protection shall be evaluated based on the activity.	PPE Category 4 – as shown in Table 1.	De-energise switchgear busbar section to be worked on, and standard non-Arc Flash PPE.	De-energise switchboard section & standard non-Arc Flash PPE
Oil-filled MV Switchgear (e.g. RMU, Primary Switchgear etc.)	Due to severity of the risk access should only be allowed in extreme cases	Local switching prohibited. Switching to be done upstream.	De-energise the entire RMU or switchboards	De-energise the entire RMU or switchboards

Table 5: Requirements for access and work in close proximity to LV switchgear.

ACTIVITY TYPE / SWITCHGEAR TYPE	ACCESS (OPENING OF DOOR COMPARTMENT OF EQUIPMENT) AND VISUAL INSPECTION	LOCAL OPERATING	SCHEDULED/ BREAKDOWN MAINTENANCE	WORKING ON FUNCTIONAL UNIT(BUCKET)	CABLE TERMINATION
Internal Arc Proof LV Switchgear	PPE Category 2 – as shown in Table 1. **Note**: the need for face and hand protection shall be evaluated based on the activity.	PPE Category 2a – as shown in Table 1.	De-energise switchgear busbar section to be worked on, and standard non-Arc Flash PPE.	1) De-energise switchboard section & standard non-Arc Flash PPE, or 2) if Incident Energy is unknown, PPE Category 4 – as shown in Table 1 or 3) If Incident Energy is known, Arc Flash PPE equivalent must be worn **Note**: it must be borne in mind that arc flash	1) De-energise switchboard section & standard non-Arc Flash PPE, or 2) De-energise all functional units (Buckets) that share cableway for the cable termination to be worked on, and PPE Category 2 – as shown in Table 1.

				exposure is higher when working inside functional unit with busbar energised hence the requirement of PPE Category 4.	
Non- Internal Proof LV Switchgear	PPE Category 2 – as shown in Table 1. **Note**: the need for face and hand protection shall be evaluated based on the activity.	PPE Category 2a if switching is done behind closed doors or PPE Category 4 if switching is done with doors open. PPE Categories as shown in Table 1	De-energise switchgear busbar section to be worked on, and standard non-Arc Flash PPE.	1) De-energise switchboard section & standard non-Arc Flash PPE, or 2) if Incident Energy is unknown, PPE Category 4 – as shown in Table 1 or 3) If Incident Energy is known, Arc Flash PPE equivalent must be worn **Note**: it must be borne in mind that arc flash exposure is higher when working inside functional unit with busbar energised hence the requirement of PPE Category 4.	1) De-energise switchboard section & standard non-Arc Flash PPE, or 2) De-energise all functional units (Buckets) that share cableway for the cable termination to be worked on, and PPE Category 2 – as shown in Table 1.
Internal Arc Classified (IAC) Miniature Substation (LV compartment) **And** **Non-Internal Arc Classified Miniature Substation (LV compartment)**	PPE Category 2 – as shown in Table 1.	1) De-energise LV Incomer & standard non-Arc Flash PPE, or 2) if Incident Energy is unknown, PPE Category 4 –	De-energise LV incomer , and standard non-Arc Flash PPE.	1) De-energise LV Incomer & standard non-Arc Flash PPE, or 2) If Incident Energy is unknown, PPE Category 4 – as shown in Table 1 or 3) If Incident Energy is known, Arc Flash PPE equivalent must be worn Note: it must be borne in mind that arc flash exposure is higher when doors open hence the requirement of PPE Category 4.	

NOTE: IAC is not valid when enclosure doors are open.		as shown in Table 1 or 3) If Incident Energy is known, Arc Flash PPE equivalent must be worn **Note**: it must be borne in mind that arc flash exposure is higher when operating with doors open hence the requirement of PPE Category 4.		

3.12 OTHER ASSOCIATED RISKS

The risk of flying particles, pressure waves and toxic gasses shall be mitigated by making sure that a task specific risk assessment be performed for any installation, operation or maintenance work on energised metal enclosed switchgear or any installation, operation or maintenance work in close proximity to energised metal enclosed switchgear.

De-energizing and remote operations remains the first choices as a means of achieving an electrically safe working condition and reducing the possibility of injury.

3.13 GENERAL RISK MITIGATIONS TO BE CONSIDERED

a. The 11 point safety plan shall be used in addition to all the requirements of this standard as part of all risk mitigations.

b. Consider available solutions detailed in the report **[9]**.

c. Consider to use remote operating’s mechanisms.

d. All new MV metal enclosed switchgear designs and installations, shall include remote motorised operations (e.g. racking).

e. Use of venting mechanisms to provide relief of pressure in the switchgear rooms in the event of an arc fault shall always be considered.

3.14 MARKING AND LABELS

3.14.1 Switchgear Labels

The labels shall only be applicable after verification by incident energy and arc flash boundary calculations. An example of the label is in **Appendix C**. The following are the content of the label:

a. Warning

b. System Voltage

c. Incident Energy

d. Arc Flash Boundary

e. Working Distance

f. Equipment Position

g. Equipment Name

h. KKS, AKZ or identification number

i. PPE Category for specific task/activity

j. Date Assessed

k. Reference to this standard for implementation.

3.14.2 Substation Door (Access door) Label

a. Flash Hazard Warning

b. Eleven Point Safety Plan

c. Reference to this standard for implementation

3.14.3 Substation room floor making

Working Distance shall be clearly marked around all the metal enclosed switchgear.

Label colours shall be: Background (yellow) and Letters (Black).

4. AUTHORISATION

This document has been seen and accepted by:

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5. REVISIONS

Date	Rev.	Compiler	Remarks
November 2012	0.1	M. Khumalo	Draft document for Review created from 36-942
December 2013	1	M. Khumalo	Final Document Authorised for Publication
March 2018	1.1	D. Monyane	Standard is revised for the following reasons, to include Tx and Dx and to be in line with NFPA 70E 2015 edition
July 2018	1.2	D. Monyane	Final Draft Document for Business Review Process
September 2018	1.3	D. Monyane	Updated Final Draft after Review Process completed
September 2018	2	D. Monyane	Final Rev 2 Document Authorised for Publication
June 2020	2.1	D. Monyane	Standard revised to remove Transmission and Distribution requirements and only present Generation requirements
August 2020	2.2	D. Monyane	Final Draft Document for Business Review Process

Date	Rev.	Compiler	Remarks
September 2020	2.3	D. Monyane	Updated Final Draft after Review Process completed
September 2020	3	D. Monyane	Final Rev 3 Document Authorised for Publication

6. DEVELOPMENT TEAM

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7. ACKNOWLEDGEMENTS

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Appendix A: ELEVEN POINT SAFETY PLAN FOR NON INTERNAL ARC PROOF/CLASSIFIED METAL ENCLOSED SWITCHGEAR

1. **Protective Clothing and Protective Equipment**: For maintenance and essential local operation, operating and maintenance staff must wear approve protective clothing and personal protective equipment to protect them against possible injury. See Generation Policy GGPP 36-941 and the 240-56179027 standard.
2. **Avoid Local Operation at Panel**. Local operation should be done via an extension lead if required.
3. **Back Access:** Limit and control access to the back of the panels.
4. **Arc Protection Boundary:** Do not move closer than the Arc Protection Boundary in front of the switchgear without protective clothing and personal protective equipment.
5. **Room Access Control:** Do not allow unnecessary people into the substation when the switchgear is alive. Limit time in room. Only authorised staff (HV regulation module 1) to have access. Others must be accompanied by an authorised person.
6. **Doors and Covers Closed:** Ensure that all doors and covers are properly closed at all times during operation.
7. **No Defects on Doors and Interlocks:** Ensure that all door hinges interlocking and locking devices are working order.
8. **Covers Fastened:** Ensure that all cover bolts are of the correct type and properly fasten.
9. **Protection Devices:** Ensure the protection settings and breaker-tripping functions are correct and checked regularly.
10. **Two Person Rule:** Two person rule applies when maintenance is done or racking of switchgear
11. **Electrical Safety Team Meetings:** Operating and Maintenance Safety meetings once a week.

Appendix B: ARC FLASH CALCULATIONS FOR EXPOSURES TO DC SYSTEMS

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Arc Flash Calculations for Exposures to DC Systems

Daniel R. Doan, *Senior Member, IEEE*

***Abstract*—Electrical systems with AC voltage have been shown to exhibit arc flash incident energy during faults. Are there arc flash hazards related to dc systems, such as battery banks for UPS or drives, or dc buses used in chemical processes? Methods are available to estimate arc flash energy of ac exposures, but not dc. This paper will show the basic equations for maximum power from a dc arc and the resulting estimated arc flash incident energy. Research is required to find accurate values, but until research is completed, these equations can help the engineer provide a preliminary estimate of the thermal energy values for applying protective clothing for these exposures.**

***Index Terms*—Arc flash, dc systems, incident energy, personal protective equipment.**

I. Introduction

ARC flash hazard assessment has been on the minds of many electrical engineers during the past few years. IEEE 1584 "Guide for Performing Arc-Flash Hazard Calculations" [1] covers three-phase ac electrical systems. The IEEE/NFPA Collaborative Research Project [2] is planning further testing in the area of dc arc flash exposure.

In the meantime, many engineers ask what amount of protective clothing is required for workers exposed to dc system hazards. These hazards can be found in large uninterruptible power supply (UPS) cabinets with battery banks, electrical room station battery sets, drive cabinets with dc buses, and special process equipment using dc buses such as salt cell processing.

Research done on the IEEE *Xplore* [3] website provided a few references for dc systems, but nothing on estimating the arc flash energy. In theory, it should be possible to develop a set of equations for the maximum arc flash energy based on standard electrical calculations that would provide conservatively high estimated incident energy values. This would be a dc version as compared with Lee's ac system arc flash energy equation [4], where the maximum energy in an ac system fault was the basis for the equation published in 1982.

The dc arc has been the object of research by Hall *et al.* [5]. These sources can provide some basis for learning about the dynamics of the dc arc. All the sources seemed to agree that the arc is highly variable and difficult to quantify. Many

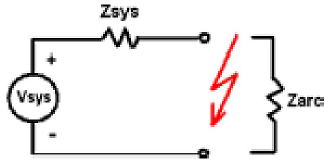

Fig. 1. Simple dc system model.

variables seem to be involved in the dynamics of the arc, such as source voltage, source impedance, gap, materials, grounding, enclosure, and environment. All these variables make it difficult to estimate the true arc flash energy exposure for a worker.

II. Basic Equations

A dc system can be modeled as shown in Fig. 1. The source can be simply modeled as a system voltage and impedance. To begin an estimate, it is necessary to make some assumptions. We can work under the assumption of a steady state of current in the arc, so that we can use the resistance of the system and the resistance in the arc for calculations. Any inductance in the system would tend to reduce the available power in the arc, so this should be a conservative assumption. Also, the inductances in the system and in the arc would tend to reduce the average power during the fault, since it would limit arcing current at the beginning of the fault.

If we consider only the resistive parts of the impedances in the simple model, arc power can be calculated by

$$P_{\text{arc}} = V_{\text{arc}}^2 / R_{\text{arc}}. \tag{1}$$

Using differential equations, we can find that the maximum power released in the arc is at the point where the resistance in the arc is equal to the resistance of the system, or when the arc voltage is half of the system voltage. Thus, (2) gives us the maximum power in the arc

$$P_{\max} = (V_{\text{sys}}/2)^2 / R_{\text{sys}}. \tag{2}$$

To convert this to the maximum energy, we need to add the time variable. As energy is power multiplied by time, (3) is our next step

$$E_{\max\text{ power}} = P_{\max} * T_{\text{arc}}. \tag{3}$$

This determines the total arc energy in watt–seconds or joules (J). To convert to the calories used in some arc flash energy, documents will require multiplying by the unit conversion of 0.239 cal/J. Combining with (2)

$$E_{\max\text{ power}} = 0.239 * (V_{\text{sys}}/2)^2 / R_{\text{sys}} * T_{\text{arc}} \tag{4}$$

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Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

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where

$E_{\text{max power}}$ total energy released at the maximum power point (in calories);
V_{sys} system voltage (in volts);
R_{sys} system resistance (in ohms);
T_{arc} arcing time (in seconds).

The arc flash incident energy estimate in calories per square centimeter (cal/cm^2) is desired. If the total energy spreads out in a sphere, it is necessary to divide by the surface area of the sphere to determine the estimated incident energy. At a working distance of D cm, the surface area of the sphere in square centimeters is

$$Area = 4^*3.14^*D^2. \tag{5}$$

So the incident energy is equal to (4) divided by (5), or

$$IE_{\text{max power}} = 0.239 * (V_{\text{sys}}/2)^2/R_{\text{sys}} * T_{\text{arc}}/(4 * 3.14 * D^2). \tag{6}$$

Simplifying,

$$IE_{\text{max power}} = 0.005^* \left(V_{\text{sys}}^2/R_{\text{sys}}\right)^* T_{\text{arc}}/D^2 \tag{7}$$

where

$IE_{\text{max power}}$ estimated incident energy at the maximum power point (in calories/cm^2);
V_{sys} system voltage (in volts);
R_{sys} system resistance (in ohms);
T_{arc} arcing time (in seconds);
D worker's distance from the arc (in centimeters).

It may be prudent to also consider multiplying by a safety factor when estimating the incident energy for arc flash in an enclosure in front of the worker. Doughty [6] showed that this multiplying factor could be as much as three times the calculated incident energy value for ac arcing incidents in enclosures.

III. Finding the Arcing Time

The difficult part is finding the arcing time for the fault. Some references discuss the operation of protective devices in dc fault conditions [5], [7], [8]. In determining the time it takes for a protective device to open, the inductances in the system and in the arc make a significant difference because the current rise is based on the L/R time constant. In Fig. 2, the effect of L/R can be seen on the current rise in the protective device. An ac waveform is shown for comparison purposes along with the current rise for dc systems with L/R equal to 2 and 10 ms.

When considering typical fuse or circuit breakers in ac systems, the opening times can be from 4 ms to a few cycles. But with dc systems, it may take longer for the current to reach the steady-state value and thus the protective device will take longer to sense the fault current and open the circuit.

With systems where L/R is under 10 ms, fuses operate in a dc system with a curve similar to that published for ac operation but with minor change at the high current portion of the curves. For L/R above 10 ms, there will be a slow increase in fault current and a correspondingly slower opening of the circuit by the fuse. In most cases, for battery banks, such as in a UPS,

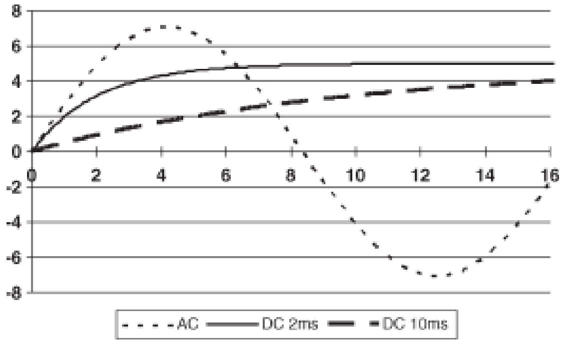

Fig. 2. Effect of L/R on current sensing.

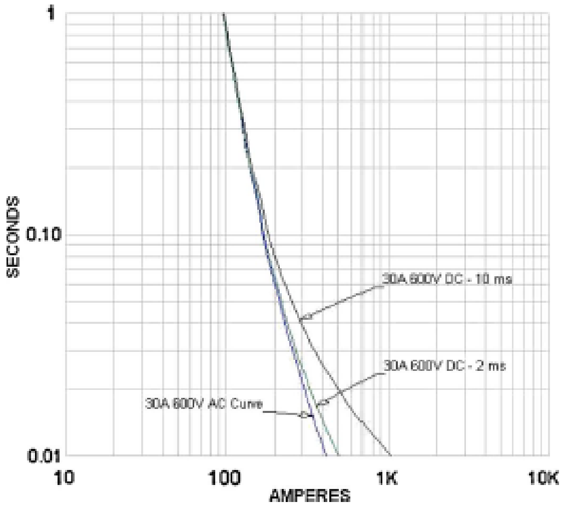

Fig. 3. Effect of L/R on fuse curve.

inductance is relatively low and 2–5 ms would be a good value to use.

The effect of dc circuit inductance on a typical 30 A fuse curve can be seen in Fig. 3, with the most effect shown in the right-hand curve with an L/R of 10 ms. This figure is courtesy of C. Cline [7].

IV. Example Calculations

A. *UPS Battery System*

The following actual calculations are shown as examples of the use of the equations. First, consider a UPS battery system with:

350-V dc bus;
10 000-A short circuit current;
$L/R = 10$ ms;
300-A fuse;
working distance 18 in (46 cm).

First calculate R_{sys}

$$R_{\text{sys}} = V_{\text{sys}}/I_{\text{sc}} = 350\ \text{V}/10\,000\ \text{A} = 0.035\ \Omega.$$

Arcing current is half of the short circuit current, since at the max power point $R_{\rm arc}$ is equal to $R_{\rm sys}$ and the current in the system is

$$I_{\rm arc} = V_{\rm sys}/(2^* R_{\rm sys}) = I_{\rm sc}/2.$$

To determine the arcing time, look up 5000 A on the 300 A fuse curve (not shown). In this case, $T_{\rm arc} = 0.2$ s, so (7) can be used to determine

$$IE_{\rm max\ power} = 0.005^*350^*350/0.035^*0.2/46^2 = 1.6\ {\rm cal/cm}^2.$$

In this case, the incident energy at the maximum power point is estimated to be above 1.2 cal/cm^2 and fire-resistant protective clothing including face protection was recommended. If typical Category 1 clothing is worn, which would normally be rated between 4 and 6 cal/cm^2, then the worker will be covered for thermal hazards well above the estimated value.

In addition to thermal protection, the worker should also be guided to wear protection for acid exposure when working around battery systems. Reference to NFPA 70E [9] or the equivalent workplace electrical safety standard in other countries is recommended to ensure that electrical hazards in general are covered by the electrical safety management methods in the workplace.

B. *Substation Battery Set*

The second example is a battery set for an electrical substation:
135-V dc bus;
1338 A short-circuit current;
$L/R = 4$ ms;
protective device unknown;
working distance 18 in (46 cm).

Calculating

$$R_{\rm sys} = V_{\rm sys}/I_{\rm sc} = 135\ {\rm V}/1338\ {\rm A} = 0.101\ \Omega$$
$$I_{\rm arc} = I_{\rm sc}/2 = 669\ {\rm A}.$$

The site could not find the specification on the protective device, so we will use a maximum value of 2 s for the arcing time

$$IE_{\rm max\ power} = 0.005^*135^*135/0.101^*2.0/46^2 = 0.9\ {\rm cal/cm}^2.$$

In this case, the incident energy is estimated to be below the 1.2 cal/cm^2 where FR clothing is required. The gloves, rubber apron, and face shield required for battery-acid protection will help protect the worker in case of an accidental arc flash.

C. *Electrochemical Cell DC Bus*

The final example is a dc bus used to power a series of process cells liberating chlorine from salt. At the base of each cell is a bypass switch, closed and opened by the operators to bypass or power each cell as needed. The bypass switch is operated by the use of a small lift, with the operator's face and body between 2 and 3 ft away from the switch.

Details of the system:
250-V dc bus;
45 000-A short-circuit current;
$L/R = 5$ ms;
dc-sensing relay and circuit breaker;
working distance 24 in (61 cm).

Calculating

$$R_{\rm sys} = V_{\rm sys}/I_{\rm sc} = 250\ {\rm V}/45\,000\ {\rm A} = 0.0056\ \Omega$$
$$I_{\rm arc} = I_{\rm sc}/2 = 22\,500\ {\rm A}.$$

The relay and circuit breaker, at that arcing current, take a total of 0.5 s to sense the current and open the circuit

$$IE_{\rm max\ power} = 0.005^*250^*250/0.0056^*0.5/61^2 = 7.5\ {\rm cal/cm}^2.$$

This value is above the value of the FR clothing normally worn by the operators in the area; their clothing is rated 5 cal/cm^2. With a longer working distance, the estimated energy could be reduced. A minimum working distance of 48 in (122 cm) was recommended to reduce the estimated incident energy to below 1.9 cal/cm^2. This would give a safety factor of approximately 3 for the workers' rated clothing. A lift with a longer reach of approximately 6 ft is now in use at the site.

V. Conclusion

This simple theoretical calculation can provide a preliminary estimated value for incident energy of DC arc flash exposures. Many assumptions have been made to enable this approach. The engineer must be knowledgeable of the system and carefully consider the hazards present in the system being studied. There may be special cases where the energy could be higher at other operating points, such as with lower power in the arc, but longer arcing time.

It would be prudent to consider using a multiplying factor for estimates calculated with these equations, if the arcing fault is contained inside an enclosure in front of the worker. It would also be prudent for the engineer to recommend a minimum of Category 1 clothing in any case, since there are so many variables, and research on the actual incident energy from dc arc flash exposures has not yet been published.

This paper was presented at the IEEE IAS Electrical Safety Workshop to begin dialogue on the issue of dc arc flash incident energy. The approach shown here is very simplistic. The dc arc is a nonlinear phenomena, so the arcing current in the dc circuit may not flow at the level which provides the maximum power in the circuit. With lower arcing current, the protective device may take longer to open, and the incident energy can be higher than that calculated. It is critical for further research to find a method of determining an estimated arcing current in these circuits. It would be possible to calculate the incident energy over the entire range of possible arcing current for the circuit, but estimating the limits of arcing current is difficult without further research.

Note: After this paper was presented, Ammerman *et al.* presented a paper "DC Arc Models and Incident Energy

Calculations" [10] that reviewed and compared many references on dc arc models and calculations. Readers are directed to study that paper for further information on this subject. Their conclusion also noted that extensive testing is needed to better understand arc flash energy in dc circuits. Hopefully, further research by the IEEE/NFPA Collaboration will be available soon.

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Mr. Doan is a member of the IEEE 1584 "Guide for Arc Flash Calculations" Working Group and is a Registered Professional Engineer in Pennsylvania.

Appendix C: AN EXAMPLE OF ARC FLASH LABEL ON THE SWITCHGEAR

DANGER

KKS NO: BBA	ARC FLASH and SHOCK HAZARD				
Substation East Board 1	11kV		Shock hazard when covers opened		
	3215 mm		Arc Flash Boundry		
Position:	15 cal/cm^2		Assesed Incident Energy		
Incomer Circuit Breaker	AFP Category				
	Activity		Breaker Racked in		Breaker Racked out
			Door Opened	Door Closed	
Equipment	Switching			Cat. 3	
11kV VCB	Racking			Cat. 3	Cat. 1
	Visual Inspection			Cat. 1	Cat. 1
Date Assessed:	Electrical Work	LV compartment	Cat. 2	Cat. 2	Cat. 2
	Electrical Work	Breaker compartment			Cat. 2
May-16	Electrical Work	Cable Compartment			Cat. 0