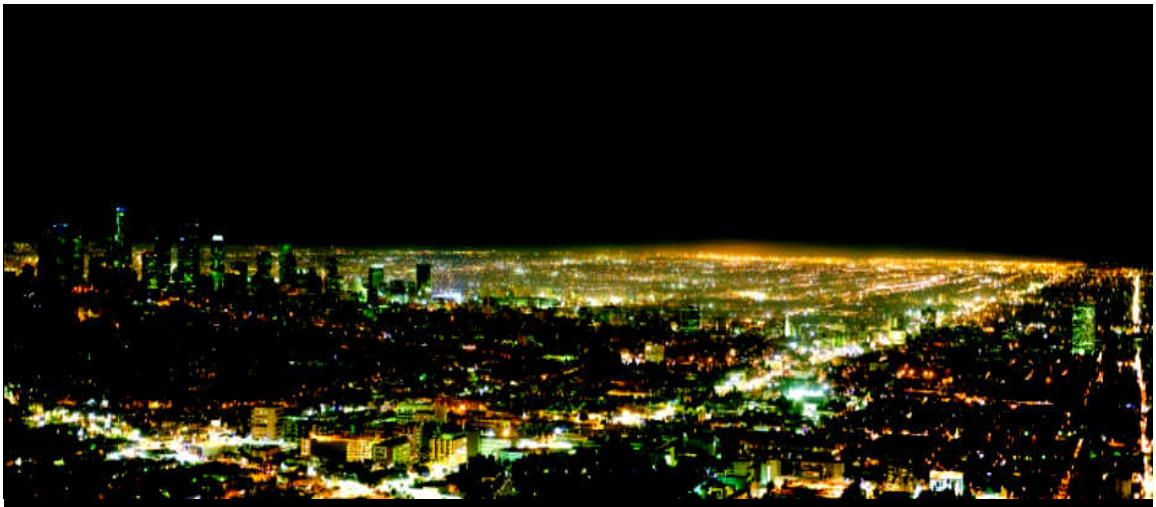


Mr. Ong Peck Seng, Assistant Vice President, Marketing, 19-02-2009

Safety aspect of low voltage switchboard

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Electric Hazards - Introduction



Electric Hazards

- ***Shock***
- ***Arc***
- ***Blast***

Arc Flash is a dangerous radiant electrical explosion.

When the insulation or isolation between live conductors fails or can't withstand the applied voltage an arc flash will occur.

This presentation is divided into

1. Electric Arc Hazards Awareness
2. Potential Risks in Switchgear
3. Arc Fault - Behaviour
4. Internal Arc Fault Type Testing
5. MNS – Arc Safety
6. Arc Monitoring Relay

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Section 1

Electric Arc Hazards Awareness

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Outdoor Substation



Transformer Arcing Fault >>> develops into a major fire

Danger Live Switchgear

It is well recognised that High Voltage (HV) Installations are Dangerous and people respect for HV

I am sure people do not have the same respect for 415V installations

- Do people take unnecessary risks on Low Voltage (LV)?
- Do you think 240V kill you?
- Will a 240V arc flash blind and burn you?
- Does a LV internal arcing fault have the same energy as

  a HV arcing fault?

Arc Flash



- Arc temperatures can reach up to 20,000 C
- Brilliant flashing light
- Extreme noise
- Hot gases, molten metal particles
- Pungent odours
- Pressure wave. 10KA, 415V arcing fault = 8 sticks of TNT
- Clothing can ignite at several meter away
- Severe or even fatal burns
- Hearing loss
- Loss of sight
- Physical injuries as a result of the blast
- Secondary faults and fires

Employee Safety

The US OSHA are enforcing **new standards** for Employee safety protection in potential arc flash situations.

- In the US there are between **5 to 10 Arc flash incidents every day**
- One utility electrical incident costs over 2 yrs was **15.75 MUSD**
- Increase in **Insurance premiums**
- In Europe, IEC standard has been enforce since Mid 90's

Arc Flash Hazard Awareness



IEEE 1584-2002 provides information on how to determine the arcing current and the arc flash hazard distance.

It shows how Arcing faults can be sustained at voltages above 208Volts with power supplies above 125KVA resulting in severe injuries especially when the arcing is inside in metal enclosures.

The standard provide guidance on the **level of PPE** that should be warn to suit the calculated incident energy.

Arc Flash Hazard Awareness

The standard looks at strategies to **minimise injuries, working de-energised, Arc Resistant Switchgear and PPE**



PPE is the last line of defence

- Heat Stress
- Poor Visibility
- Limited Body & Hand Movement

The standard states it is not intended to imply that wearing PPE makes it allowable to work on Live equipment

Arc Flash Victim



Reference IEEE 1584 -2002

Electrician Switched Off the isolator, opened the compartment door, to replace a 400A fuse

Safety equipment , Hat and Glasses

Peter Wiebe was engulfed in the discharge of the
arc flash products , he survived.

- Third degree burns to 28% of his body. Resulting in years of skin grafts
- Significant loss of hearing, tinitus – Hearing Aids
- Server headaches when trying to focus less than a meter
- Loss of smell
- Vestibular function damage

Australian Cement – Arcing Incident



1999 Pre heater Failure Railton Plant

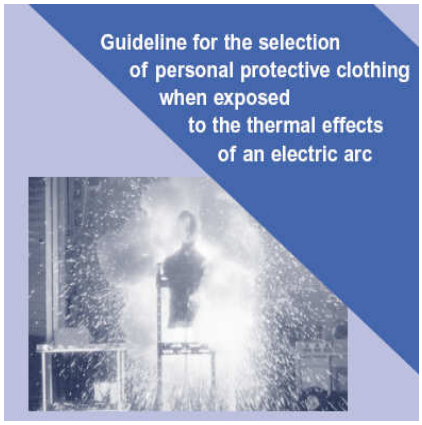
- Substation was unattended
- Plant was out of action for 4 weeks
- Loss of production 8MUSD

Solution

- Strategies implemented to prevent / minimise happening again.
- Clean up Switchrooms – Filters
- Check and up grade protection
- ABB Arc Guard
- ABB Arc fault contained switchgear
- On –Line condition Monitoring

ISSA - Guidelines

International Social Security Association



The Guideline contains on PPE

- Selection (European Directive 89/686/EEC/1)
- Calculations on heat stress
- Testing (IEC 61482-1)
- Testing (ENV50354:2000/4)
- Classification and Rating System (Stoll)
- Recommendations and Cleaning

ISSA - Guidelines

International Social Security Association



Testing at 4kA/500ms – Flammability of Fabrics

- Insulate from the exposed heat energy
- All fibres natural or synthetic can burn to some degree
- PPE can't guarantee 100% protection
- PPE can only be classified as Flame – Resistant

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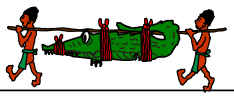
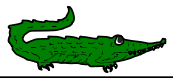
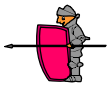
ABB

A matter of milliseconds

Employee Safety

TOP Principle (Technical - Organisational - Personal) on the 4 Level – Strategy

1. Elimination
2. Distance
3. Containment
4. Personal Protection

Risk	Personal	Action
		**Eliminate the risk**
		**Keep distance to the risk**
		**Contain the risk**
		**Personal protection against the risk**

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Employee Safety- TOP

- **1st Level:**
  Eliminate the risk >>> Switch off and work under de-energized conditions
- **2nd Level:**
  Keep distance to the risk >>> Lock the switchgear room and work from remote
- **3rd Level:**
  Contain the risk >>> Use arc fault contained electrical installations

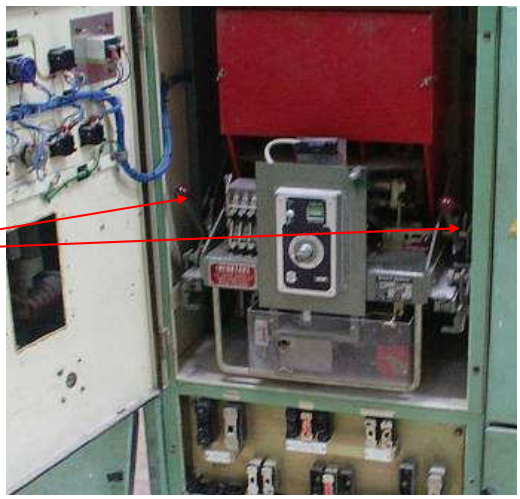
  If this doesn't help to execute the task, then apply the 4th level to limit the risk
- **4th Level:**
  Personal Protection against the risk >>> Use permitted PPE during work to limit the risk

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Case Study

With ageing switchgear there is a very significant risk of component failure when performing the rack-out or rack- in procedure.

Racking handles



This failure may result in an Arc Flash
Risk Analysis calculated the Arc flash level of approx. 10kVA

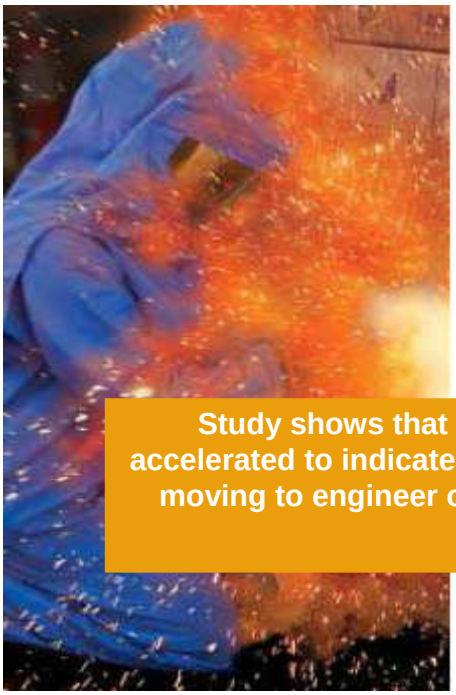
Wear a Cat 4 suit to Rack in & out

Cat 4 PPE
improves the protection
against an Arc flash





Cat 4 level PPE reduces the risk



PPE can't guarantee100% protection
PPE can only be classified as
Flame – Resistant

Arc flash analysis- Recommendation :

Study shows that the replacement program should be accelerated to indicate to the workforce and recommendation is moving to engineer out safety issue rather than resorting to wearing of PPE

Employee Safety

The following actions are being taken by some owners to improve the safety in their existing switchgear

- Installing IR windows in compartment doors
- Use of Long handle tools
- Remote racking and closing of circuit breakers
- Installing Current limiting fuses
- Installing Panel isolators
- Installing smoke detectors
- Installing Arc detection equipment
- Installing Earth fault protection
- De - energise before entry to the switchgear
- Enforcing PPE

  Progressing to :
- Replacing the switchgear w/- " Arc fault contained switchgear "

ABB Philosophy in Switchgear Design- Level 3

- Arcing faults should be ***prevented*** from occurring in the first place by designing and dimensioning the system correctly and using materials that actively do not support Arcs
- The Main Bus bars should be way from the operator at the rear in a segregated compartment. Bus Bars should be ***maintenance free.***
- The starter and feeders units should be fully withdrawable so they must be isolated and removed for maintenance (so you ***can't work on "live" equipment***.)
- All switching & racking operations are done with the compartment ***doors closed***.
- All switchgear is to be ***proven safe*** by Internal Arc Fault containment Type Tests in accordance with the relevant standards and certified by independent body.

End 1
Back



Section 2

Potential risks in switchgear

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Potential Safety Risks in Switchgear

SHORT CIRCUITS

It is well recognised that the dynamic and thermal forces, as a result of a bolted short circuit on the busbar, have the potential to complete destroy the switchgear.

OVER TEMPERATURE

Overheating of a component can very easily cause thermal runaway inside a switchgear compartment.

This can soon develop into arcing and fire which has the potential to completely destroy the switchgear.

Overheating is a major risk to people and plant.

Potential Safety Risks in Switchgear





ARCING FAULTS

- Arc flash as a result of accidental contact with live parts when operating or working on switchgear happens far to often.
- Internal arc faults are more of a potential hazard to life and limb than a bolted short circuit .
- Arcing fault can develop into a major fire that can destroy the complete switchboard and even damage the surrounding plant.
- Arc can produce enormous gas pressures and extreme temperatures. Personnel in the path of super-hot gases created by the arc, can be **killed** or suffer serious burn injuries and therefore confining arc faults is a very important topic.

What causes internal arcing faults

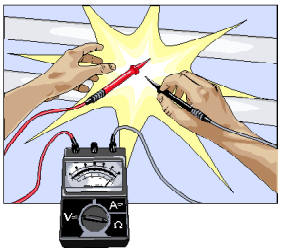
- More than 80% of arc faults are due to human error.

  Forgetting to remove testing/earthing fuse wire wrapped around busbar or other live parts. Leaving screwdrivers/spanners and swarf behind after maintenance. Or worst still accidental contact or bridging out live components during testing , fault finding or doing modifications
- Unforeseen accidents/problems, overheating of connections or components, secondary arcing as a result of the presence of ionised gasses, over voltages and penetration of vermin, ingress of water.
- Improper work & maintenance practices

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What causes internal arcing faults

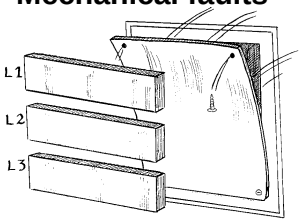
Human Errors



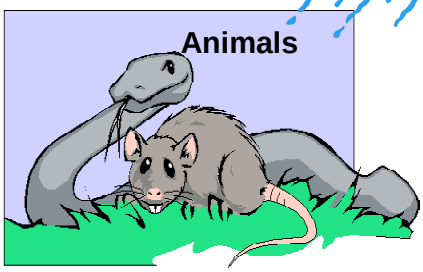
Pollution



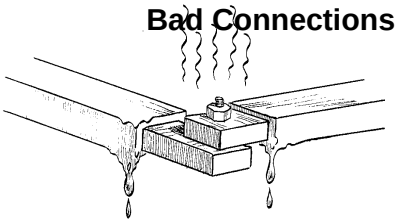
Mechanical faults



Animals



Bad Connections



End 2 Back

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Section 3

Arc Fault -Behaviour

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Arcing Fault behaviour

Not all arcing faults are an instantaneous electrical explosion.

There are a number factors:

- The fault level
- The gap distance
- The voltage
- The switchgear materials and construction
- The protection equipment
- How the arc was created

Types of Arcs

SWITCHING ARC

The prime function of switchgear is to switch on & off electrical circuits. Interrupting a current results in arcing between the contacts. There are many types of interrupters with many ways of arc extinction.
The interrupters *control* the arc.

Then there are unconstrained free burning fault arcs. To know how best to *contain* these arc we need to know more about the arc behaviour.

Types of Fault arcs

- Travelling Arc
- In-Line Arcing
- High impedance Arcing Faults

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Switching Arcs



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Arcing Fault behaviour

TRAVELLING ARC

Experiments in the 1950's showed that if an arc was initiated on a 3 phase bus system by a fuse wire the arc and the resultant Ionised gas would travel along the bus at speeds greater than 100m/sec – There is little damage until the arc is impeded.

Then there is an arc explosion

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ABB

Travelling Arc



Arcing Fault behaviour

IN-LINE ARCING

A poor plug contact or connection resulting in a gap in the conductor will result in an arc. In the case of a motor the arc current is the Motor current. This can then eventually result in secondary arcing faults or overheating and fire.

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In line Arcing



Arcing Fault behaviour

HIGH IMPEDANCE ARCING FAULTS

Phase to earth fault develops with time into a phase to phase arcing fault

Arcing Fault, Thermal Runaway, Fire

It is not always clear how the fault is initially started



Caption: An MCC panel, incomer, bus tie, incomer

We suspect this was a high impedance Arcing fault in one compartment producing very high temperatures

The high temperatures resulted in spontaneous combustion in the adjacent compartments

Arc Energy

Arcing Accidents... a matter of milliseconds





The damage resulting from an arcing accident depends on the **arcing current** and the **time.**

Of the two parameters **only the time can be influenced,** i.e. Reduced to a minimum

Internal arc fault- Pressure

- **COMPRESSION PHASE**

  lasting 5 – 10ms:
  Pressure increases inside the switchgear, exerting forces onto the enclosure

- **EXPANSION PHASE**

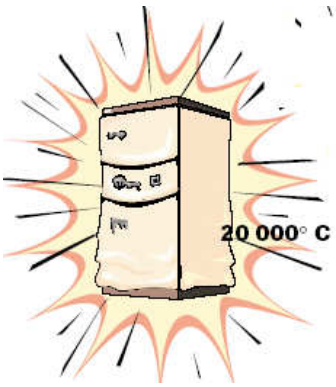
  lasting 5 – 10ms:
  Creates a wave like movement



Internal arc fault – Ionised Gasses

- **EMISSION PHASE**

  lasting 50 – 100ms (if not impeded): At this point the ionised gasses from the arcing fault reach the outside of the switchgear and will continue to flow until pressure equilibrium is achieved between the inside and the outside of the enclosure



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Internal arc fault - Fire

- **THERMAL PHASE**

  This ends only when all available fuel has been expended, or the fault interrupted, with the heat energy acting on the equipment vaporising and melting metal and insulating parts.



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Arcing Fault protection

We believe the only way to be verify Arc Fault protection is by conducting ***Internal arc fault containment type tests*** on the particular switchboard for the actually operational conditions.

Not by :

- Arc flash calculations or
- Wearing PPE or
- Only relying on the Short Circuit Protection Relays

End 3
Back

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Section 4

Internal Arc Fault Type Testing

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Milestones of internal arc safety

1960‘s LV MCC to BS4070 Arc fault Tests In Australia

MV Arc Fault Testing in Germany to Pehla recommendations

1974 ABB performed first internal arc tests MV IEC 298.

AS 1136 LV Arc Fault Testing Included

1985 ZVEI in Germany release guideline LV internal arc tests

1996 LV guideline for internal arc fault **IEC1641,**

2002 **AS/NZS 3439.1:2002 LVInternal arc fault test included**

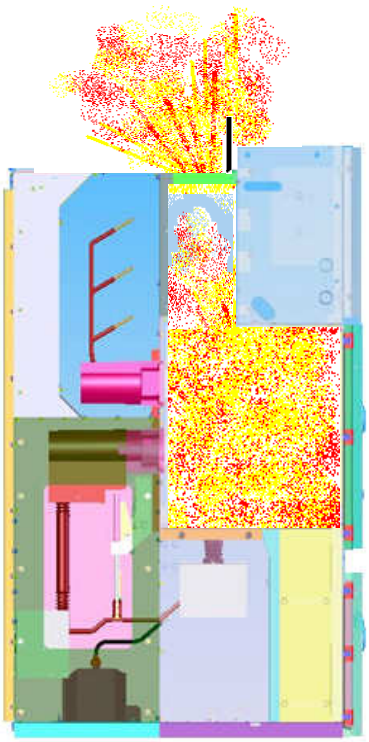
2003 IEC 62271-200 supersedes IEC 298. enhanced Internal arc fault test included

2005 **AS 62271-200** supersedes AS 2086. enhanced Internal arc fault test included

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Arc Fault Testing of Large LV & MV Panels

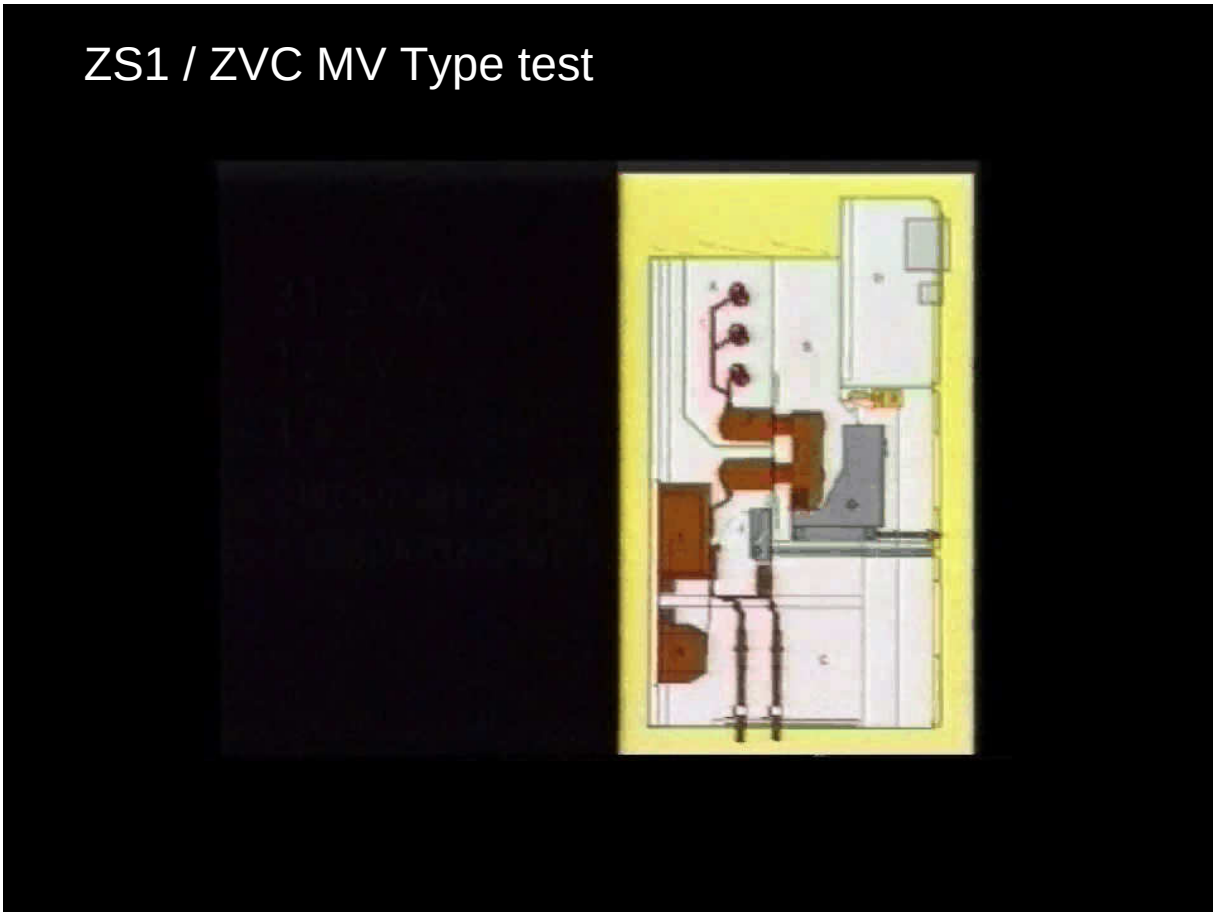
- Compression & Expansion Phase
- Emission Phase
- Thermal Stage



Cross section of a typical **LCS2B switchgear unit** (ABB ZS1)

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ZS1 / ZVC MV Type test

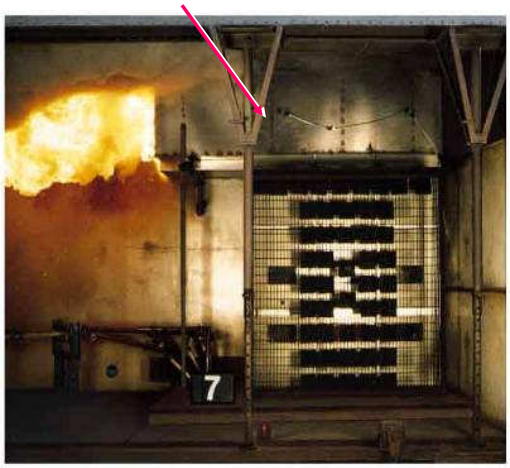


ZS1 / ZVC MV Type test

Arc-proof tested

Tested according to IEC 298 standards, appendix AA, class A, criteria 1 to 6
AS 26671-200 appendix A class A criteria 1 to 5.

Arc Duct



CRITERIA

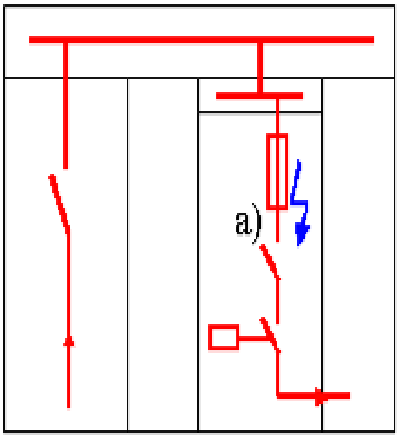
1. Correctly secured doors, covers do not open
2. Parts which may cause a hazard do not fly off
3. No holes in the freely accessible external parts of the enclosure.
4. Vertically arranged indicators do not ignite.
5. Horizontal arranged indicators do not ignite.
6. Earthing connections are still effective.

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Arc Fault testing

Testing AS/NZS 3439.1;2002

In the **" Standard " arc fault containment** tests set out in LV standard AS/NZS 3439.1, the arc is initiated on the load side of the functional unit protection device. (a)

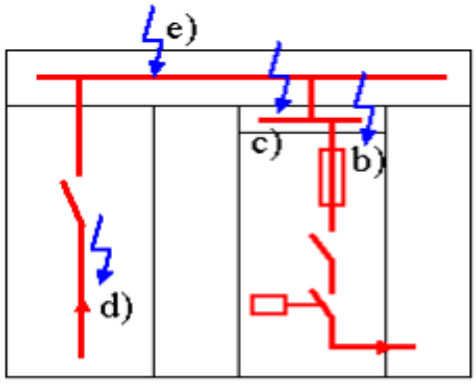


This was called a **"Limited "arcing fault** under the old AS 1136 standard. The protection device limits the let through energy. Typically on small motor starters protected by HRC Fuses the arc duration is around 2 milliseconds and the resultant damage is minimal. Typically on Larger motor starters, protected by conventional circuit breakers, the arc duration can be in excess of 40 milliseconds and here the damage is quite substantial.

Arc Fault testing

Testing AS/NZS 3439.1;2002

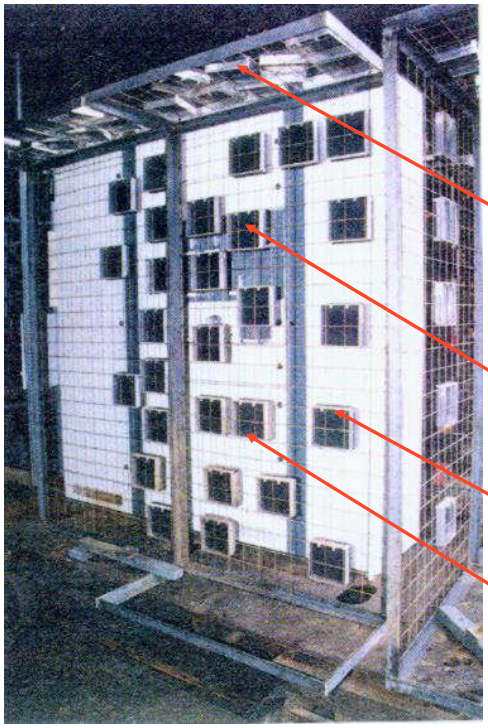
The longer the arcing time the greater risk of the arc developing into a line side fault or secondary arcing on the **distribution busbars**. (b & c)



Under AS1136 this was called **"Unlimited" Arcing Fault**. In AS/NZS 3439.1 these unlimited tests are called **"Special Tests"**. The fault current is only limited by the testing Lab max. 300 ms.

Main bus (e). The fault current is only limited by the testing Lab max. 300 ms.
The fault arc runs to the end of the busbars. **"Travelling Arc"**

LV/MV Type test set up



Test arrangement, MNS with cotton indicators at critical places

Horizontal indicators are only required in medium voltage

Vertical cotton indicators up to 2m height

Cotton indicator

Switchgear front

© ABB Group

Assessment of Arc Test Results

IEC61641Test criterion 1- 5 for Personnel Protection: Criterion

- Correctly secured doors, covers, etc., do not open
- Parts (of the assembly), which may cause a hazard, do not fly off
- Arcing does not cause holes to develop in the freely accessible external parts of the enclosure as a result of paint or stickers burning or other effects
- The indicators arranged vertically do not ignite (indicators ignited a result of paint or stickers burning are excluded from this assessment
- The earth bonding arrangement for accessible parts of the enclosure is still effective

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Assessment of Arc Test Results

VDE0660 part 500 (draft 2001 march supplementary sheet 2) Test criteria for Plant Protection including System Function Protection Criterion

- The arc must be limited to the defined area and must not re-ignite in the adjacent compartments
- An emergency operation of the switchgear and control gear assembly must be possible when the fault has been repaired and/or the functional units of the defined area have been isolated or removed. This requirement must be evidenced by an insulation test carried out at 1.5 times the rated operating voltage for 1 min.

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Internal Arc fault containment test



100kA, 690V, Arc duration 200ms – Failed Test

Internal Arc fault containment test



Pressure blows the door open

ASTA TEST REPORT COPY

Laboratory Ref. No: 1117.1523.6.771 **Test Report No.** 2192

APPARATUS: Low-voltage switchgear assembly consisting of:
- a three-phase and neutral main busbar system,
- a three-phase and neutral distribution busbar system,
- a horizontal protective busbar,
- 5 outgoing withdrawable modules

MANUFACTURER: ABB Malaysia Sdn. Bhd. (210262-T)
Lot 607 & 808, Jalan SS 13/1K
47500 Subang Jaya
Selangor Darul Ehsan, MALAYSIA

TESTED FOR: ABB Automation Products GmbH
Wallstadter Straße 59
68526 Ladenburg, GERMANY

TESTED BY: Institut „Prüffeld für elektrische Hochleistungstechnik" GmbH
Landsberger Allee 378A
12681 Berlin, GERMANY

DATE(S) OF TESTS: 9 December 2006

The apparatus, constructed in accordance with the description, drawings and photographs incorporated in this test report has been tested in accordance with Client's instructions.
The test procedure and test parameters were based on

AS/NZS 3439.1: 2002

Internal arc-fault test with a prospective short-circuit current of 100 kA at a rated operational voltage of 690 V and a prospective duration of short-circuit of 300 ms

This is not a certificate of rating.
A certificate of rating was not issued as this test is not a type test or a compulsory test.

The documents forming this Test Report are:

Record of Proving Tests:	Page 1 to 53
Diagram Nos.	1
Oscillogram Nos.	1067149, 1067151, 1067152, 1067153, 1067154, 1067159, 1067160
Photograph Nos.	1 to 37
Drawing Nos.	1TPE902001D0203 PAGES 1 and 2

The Record of Proving Tests applies only to the apparatus tested. The responsibility for conformity of any apparatus having the same designation with that tested rests with the Manufacturer.

UKAS PRODUCT CERTIFICATION 010

ASTA Observer H. Glabsch

DIRECTOR

31st May 2007 Date

Reproduction of the complete Test Report only is permitted without written permission from ASTA BEAB Certification Services, Hilton House, Corporation Street, Rugby, Warwickshire, CV21 2DN UNITED KINGDOM.

- Internal arc – Fault Test Report
- AS/NZS 3439.1;2002
- 100kA 690V prospective 300ms
- MNS Withdrawable Modules 4E,6E,8E,16E,24E.

MNS Starter Unlimited Arcing Tests



MNS Starter Unlimited Arcing Tests

- Starter Modules 4E to 24E tested to **IEC61641**
- Rated Volts 440, Permissible 80kA , 300 ms
- Owing to the construction of the contact holder the ignition wire can only be inserted from inside the module. The rear wall is removed, the cable plugs are also removed and the wire is attached to the plug and reinserted

Ignition wire

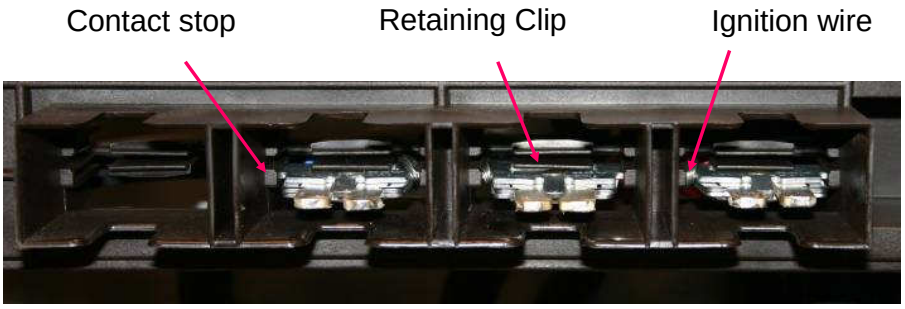


View from inside the module

© ABB Group

MNS Starter Unlimited Arcing Tests

- Starter Modules 4E to 24E tested to **IEC61641**
- Rated Volts 440, Permissible 80kA , 300 ms
- Each contact is fully shrouded and segregated from the adjacent contact. Arcing between contacts points when the module is inserted is impossible.



View from rear of module

MNS Starter Unlimited Arcing Tests

24E Module after 80kA Unlimited Arc tests



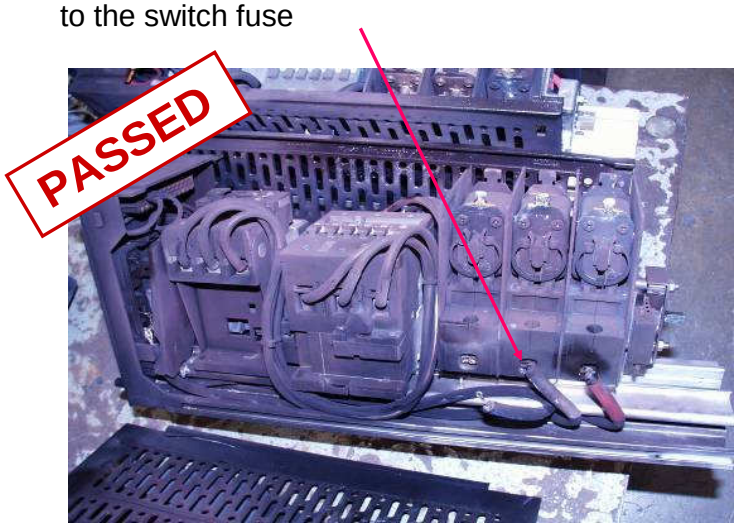
Arcing on the inside of contact plugs

No arcing on contact points

MNS Starter Unlimited Arcing Tests

8E/4 Module after 80kA Unlimited Arc tests

The only accessible line connection is where the double insulated cables connect to the switch fuse



The only accessible line connection is where the double insulated cables connect to the switch fuse

MNS Main Bus Arc fault Testing

80 kA, 440V, Arcing Tests to IEC61641

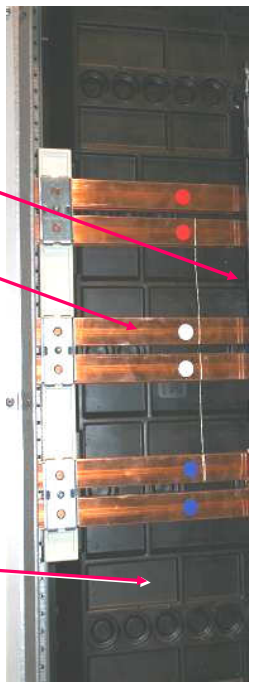
Ignition wire

Main Bus 4 x 40 x 10 cu / phase

Test data

- Rated Volts 440
- Permissible Prospective current 80kA
- Permissible Duration 300 ms

Multi-functional wall (MFW)



MNS Main Bus Arc Fault Testing

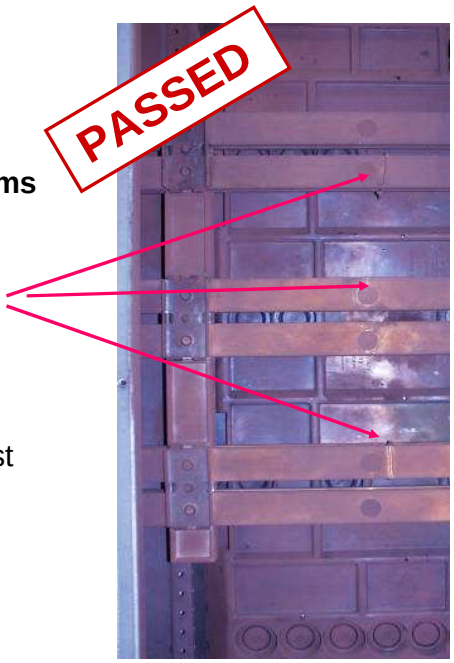


MNS Main Bus Arc fault Testing

Test Results

Passed IEC61641

Arc Duration the full 300ms



- No sign of arcing
- Thick layer of copper dust
- Travelling Arc

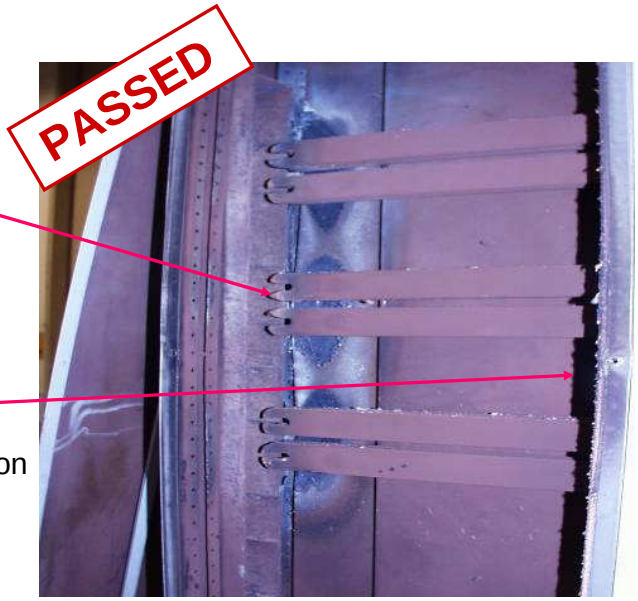
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MNS Main Bus Arc fault Testing

Traveling Arc

The Arc traveled along the bus to the end of the switchgear where there was extensive Arcing for 300ms

Pressure cause this very substantial construction to deform

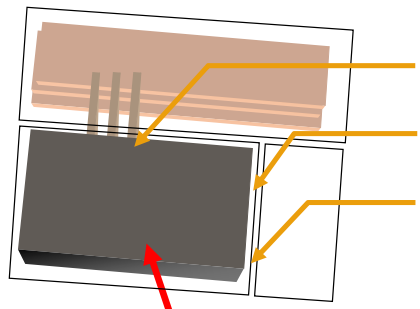


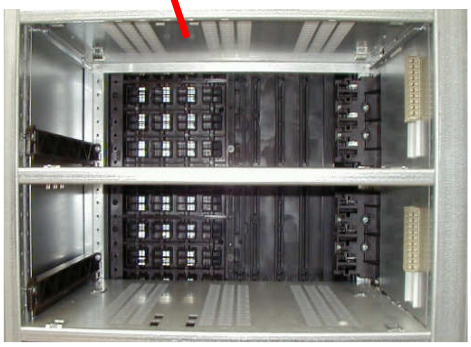
The arcing fault was contained

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February 26, 2009 | Slide 63

MNS compartments - Arc Fault contained

Module connection principle





Safety Aspects

- Starter removed for inspection
- Segregated compartments Form 4
- Arc Fault contained
- Busbars are Insulated and Phase segregated
- Bus connections are finger proof IP2X

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Arc Flash demonstration

3 phase arcing fault , inside a wooden box



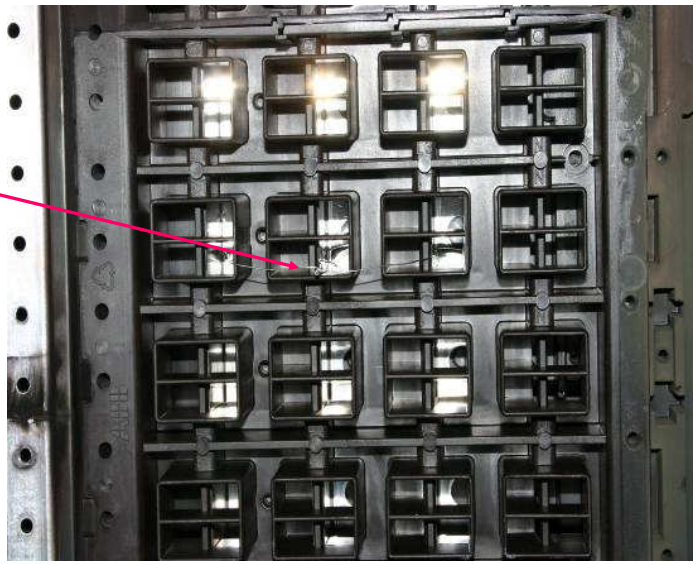
MNS Distribution Bus

The bus cover was removed
The ignition wire was attached to the busbar and the cover was refitted.

The door was removed for the test

Test data

- Rated Volts 440 Permissible
- Prospective amps 80kA
- Duration 300 ms



MNS Distribution Bus



MNS Distribution Bus

No Damage to the MFW

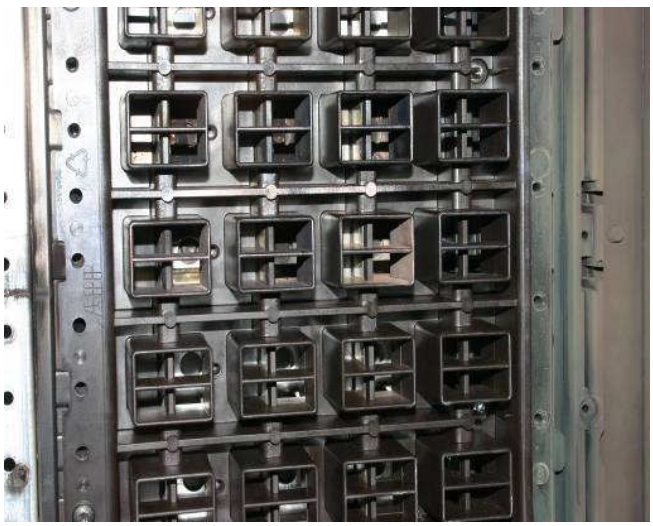
Results of Test

Let through energy

- R= 469 kA^2S
- W=106 kA^2S
- B= 221 kA^2S

Arc Duration

- R= 6.8ms
- W=6.8ms
- B= 3.4ms



After Test

MNS Distribution Bus

Arc Flash calculation based on IEEE 1584 and the test results obtained at T&C

Fault Current in kA rms (Ibf)	3.02
Arc Duration in ms (t)	6.8
Voltage level in V (V)	440
Bus bar gap in mm (G)	50
Working Dist in mm (D)	400
Incident Energy in cal/cm2 (E)	0.56
PPE Category	0
Flash Boundary in mm (DB)	251

This calculation supports ABB's 20+ years practical experience with MNS

Withdrawing a starter from a "live" bus without any special PPE is *SAFE*

End 4 Back

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Section 5

MNS- Arc Safety

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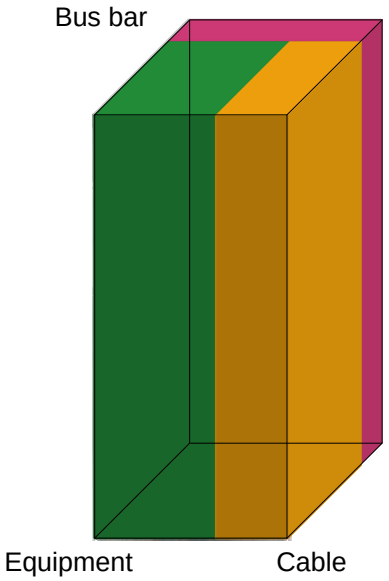
Power and productivity for a better world™

ABB Philosophy in LV Design- Level 3

- Arcing faults should be ***prevented*** from occurring in the first place by designing and dimensioning the system correctly and using materials that actively do not support Arcs
- The Main Bus bars are ***maintenance free*** and located way from the operator at the rear, segregated behind an arcing barrier. (option insulation to provide addition arc fault protection)
- The Distribution bus bars are to be insulated and phase segregated so it is virtually impossible to create secondary arcing faults. ***Fault Free Zone***
- The starter and feeder units are fully withdrawable so they must be isolated and removed for maintenance .

  No Need to work on "live" equipment.
- All switching & racking operations are done with the compartment ***doors closed***.
- MNS is Type Tested for Unlimited ***Arc Fault containment***

Cubicle compartments



Functional rooms in a cubicle

Maintainable from the front

Internal segregation for

- Superior operator protection
- Separate access for
  - Maintenance
  - Extensions
  - Retrofits

Withdrawable Starters are Safer

The Starter can be withdrawn and isolated for inspection.
No need to work on “Live Equipment”

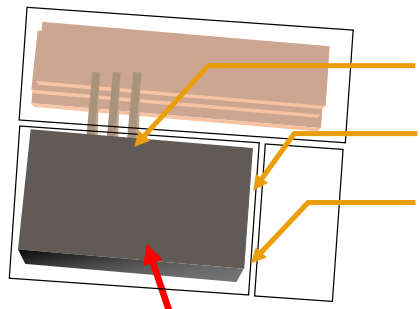


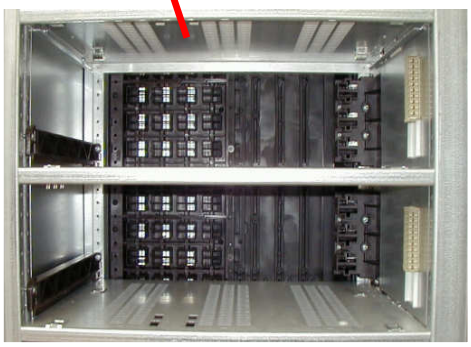
CRITERIA

- High personnel safety, arc fault contained in all positions
- Easy to Change - Minutes interlocked, safe, no tools
- Easy to Maintain, 3 module positions: Operation, test and Isolate
- Total Visual Isolation
- Compact – Smaller foot print

MNS compartments - Arc Fault contained

Module connection principle



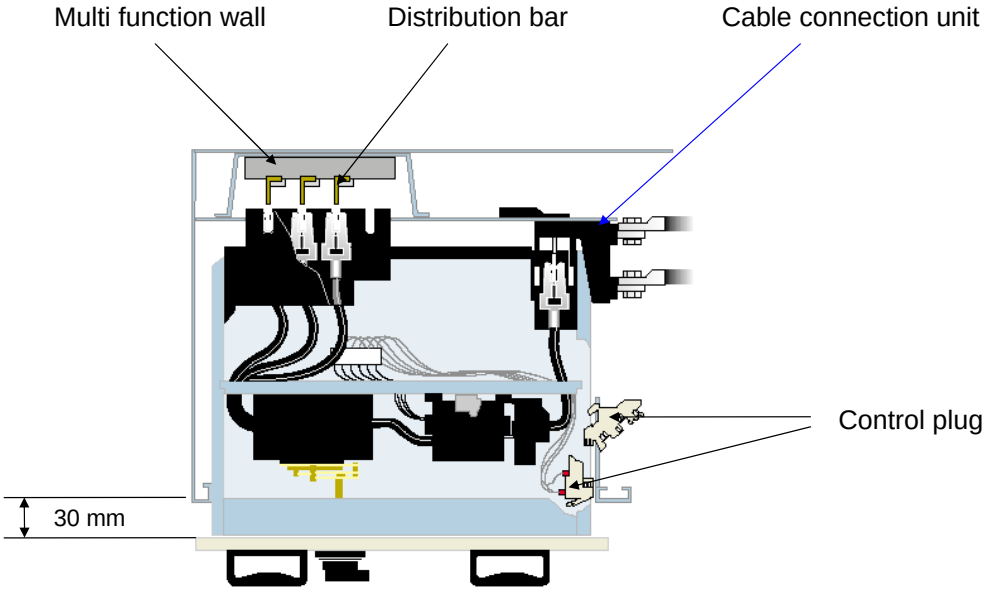


Safety Aspects

- Starter removed for inspection
- Segregated compartments Form 4
- Arc Fault contained
- Busbars are Insulated and Phase segregated
- Bus connections are finger proof IP2X

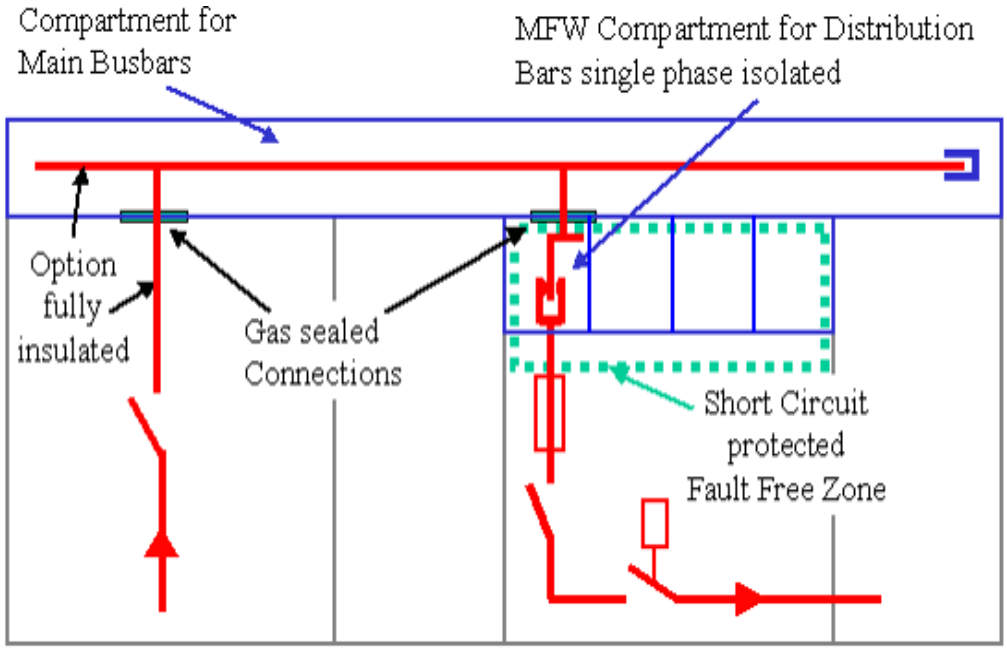
MNS – Modules 4E...40E

Example: Motor starter



Module interlocked in disconnected position

Fault Free Zone



End 5
Back



Section 6

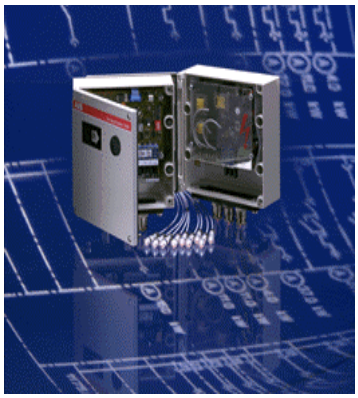
Arc Monitoring Relay

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Arc Monitoring Relay

- **Optical detectors detects the light from the arc**
- **The Arc Guard Monitor immediately trips the breaker**



"The watchful eye"

Wide angle sensitive lens to detect any arc fault

Fibre optical cable to ensure immunity



© ABB Group

Arc Monitoring Relay



The Arc Guard Monitor

- **Intelligent monitoring unit**
- **The “brain” of the system**

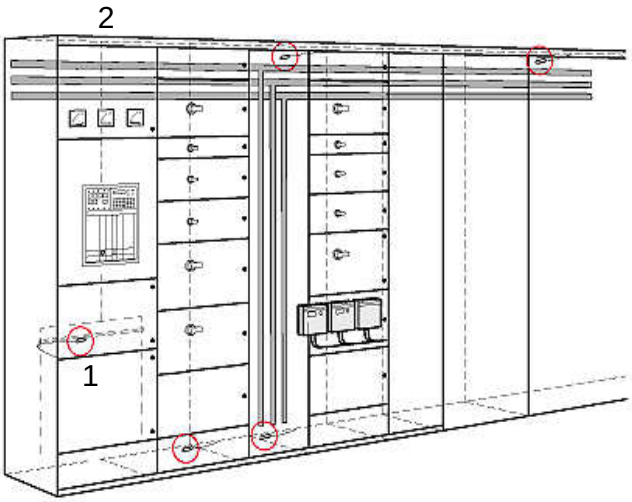
Arc Monitoring Relay

With ABB Arc Guard System ....
....the whole switchgear assembly can be monitored

Example showing the position of detectors in a Low Voltage Switchgear:

1 In a circuit breaker cubicle

2 In the horizontal bus-bar system



Unlimited Arc Fault Containment

With every update of the ABB MNS switchgear design the original design criteria of arc fault containment, to minimise the risks to personnel and plant, have been maintained.

Over the last 30 years more than **400 arc fault containment tests** have been conducted on MNS switchgear.



The MNS functional units have been **tested for both limited and unlimited arc fault containment.**

World wide we supplied **>1,000,000 panels of MNS in service** making...
ABB the leader in LV Arc Fault Containment Technology.

Power and productivity
for a better world™