Design of a New Generation of Internal Arc Resistant Switchgear

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Abstract

Although rare in service, an internal arc fault cannot be ruled out completely, and so manufacturers are now designing equipment to withstand internal arc faults, and to minimise the consequences of an internal fault. The standards for the requirements differ considerably, as for example, the requirements of ANSI are not the same as for IEC. But the standards are continuing to evolve as this issue becomes more understood.

The design of a new range of withdrawable metal-clad cubicle must provide the maximum safety to operating personnel and cope with a number of different demands, including the ability to limit the consequences of a fault to the compartment in which it occurs. These cubicles shall be built with segregated compartments, doors and front covers designed to withstand severe stresses without allowing the effects of the arc to come outside. The paper describes the design of MV switchgear with respect to internal arc, both from an operational and from an operator safety point of view.

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1. Introduction :

An internal arc fault, though rare in modern, well conceived, properly planned substations, cannot be ruled out completely. Such a fault might occur due to one of several reasons which are difficult to control, including failure of insulation or contacts due to ageing, failure of instrument transformers and overvoltages in system because of switching or lightning surges, pollution due to environmental conditions, maloperation or insufficient maintenance.

An important fact is that the probability of occurrence of an internal fault is very much reduced by special design of easy handling of the equipment, the choice of selected and tested materials, proper and adequate insulation, use of electrical and mechanical interlocks. Moreover rigorous factory testing on components and products after final assembly also helps a great deal to improve the quality of the product. A good documentation of all functions including instructions of proper handling will also help to reduce the occurrence of such faults to a great extent.

One possible approach is to use quick arc detecting device and quick fault clearing relays, which will certainly help to keep the damage from such a fault to a minimum, and these are available as options on this equipment. However these are active systems to prevent damage, and as such there is a possibility that they may fail to perform, or operate. Whatever we do, the possibility of a fault occurring still remains, and so it is necessary to develop switchgear which can cope with an internal arc in a safe way, using passive design techniques to minimise damage within the unit as well as to the building and other adjacent units.

Such a modern arc resistant metalclad medium voltage air insulated switchgear is now available to cope with even this rare occurrence of internal fault, covering voltage and current ranges from 3.3kV to 27 kV, 630A to 5000 A, and with a short circuit capacity up to 50 kA.

Several standards presently exist or are being currently developed to cover internal arcing, and for information the key differences between the new IEC and ANSI standards are listed in an Annex.

2. The physical phenomena:

To understand the effects of an internal fault one should consider the physical process a little more in detail.
The first phase (compression) starts with the arc ignition and ends after reaching the maximum pressure in the corresponding compartment. The enclosed air in the compartment will be heated depending on the arc energy with the pressure relief flaps closed. The pressure in the compartment rises which is directly proportional to arc fault current and the length of the arc and indirectly proportional to the volume of the faulted chamber. The duration of the compression phase and the maximum pressure rise depends on arc energy (arc fault current and arc voltage) and the volume of the chamber in which the fault occurs, as well as some other factors such as place and position of ignition, and any air circulation openings.

The second phase (expansion) is when the maximum pressure peak is reached and the pressure relief system operates to bring down the pressure. In this phase the compressed air is vented from the faulted chamber through a specifically designed duct.

In the third phase (emission) the remaining air will be heated further and driven out with the pressure relief flaps open. The remaining air in the compartment will reach the arc temperature. In this stage almost all of the air in the compartment is driven out.

The last phase (thermal) in the process now lasts up to the end of arc duration. In this stage the arc energy is applied completely towards the fixed parts inside the compartment. This results in melting and vaporisation of copper connections, feeders, switching devices, metal parts of the enclosure, as well as the plastic and insulating materials. The erosion of material depends mainly on the duration of this period and is also dependent on arc current value, together with the specific thermal characteristic of material used as well as the distance of the switching equipment from the arc root.

The complete process of internal arc inflicts two heavy stresses on the equipment, which can be described in short as follows:

- <u>Mechanical stress</u>

The pressure rise affects the faulted compartment in distortion of the main and the partition walls. The fixing elements such as bolts and nuts or the hinges or the fixing points of doors or covers or flaps are stressed by strain or shearing forces.

To tackle this problem special materials are carefully chosen and special bending forms of sheet metal are necessary which will withstand these stresses without undue damage or deformation.

- <u>Thermal stress</u>

For the whole duration of the fault material will be eroded and vaporised at the arc root. This consists mainly of the copper parts in the vicinity of the arc, but other materials such as metal walls or partitions may also be melted and vaporised, and if this happens hot gases may be allowed to escape outside. The plastic and insulating parts used in the switchgear equipment are also heated up and may under the circumstances be vaporised.

The insulating material should be so conceived so that it does not continue to burn after the extinction of arc and that it does not release any toxic or corrosive elements which may increase the indirect damage.

3. The standardisation and its evolution:

In the early sixties the problems and consequences of the internal arc fault was not given much attention, as at that time the problem was not properly understood. In the course of mid sixties it was evident that a common need for equipment with some internal arc withstand capability existed, and therefore the necessity of a common standard was felt. Within the next decade this phenomenon attracted increasing attention and PEHLA in Germany came up with the first standard which was immediately hailed as a new theme in the branch of metal clad equipment.

Both ANSI and IEC have now realised the importance of designing for protection against internal arc and are now discussing on this subject in their own working groups to introduce internal arc in the latest version of the standards. A comparison (as shown in the annex) of the specifications IEC IEC62271-200 and IEEE C37.20.7 shows the main differences between these two standards. The main differences are mainly due to different customer demands and market requirements. It is believed by the authors that as time goes on the design of internal arc resistant equipment will become more and more common as customers understand and see the benefits of this type of design.

4. The design

The new design of a metal-clad switchgear has to cope with the internal arc faults and importantly keep the effects of arc confined in the place of occurrence, allowing continuous operation of the remaining functions not associated with the fault. Special attention has to be given to the design of the doors and the front covers which must withstand severe stresses while not allowing any damaging effects outside the faulted compartment. Care has also to be taken to design the pressure relief flaps of circuit breaker and busbar compartments so that when the flap of circuit breaker compartment opens it will not contaminate the busbar compartment or vice versa. Apart from this, measures also have to be taken to avoid any burn through or penetration of the compartment walls. In particular the inspection windows have to be designed with special care. Measures have to be taken also not to allow any part to fly away during such a fault. To complicate matters further such a new design also has to be available with walkways and/or access at the front, rear, or on the sides as desired.

An example of arc resistant switchgear cubicle according to new design is shown in paragraph 6, and is the result of putting these ideas into practice. The concept of such a design is to use very simple technologies, that allow world-wide manufacturing possibilities with a good level of quality but without using sophisticated tools.

Importantly the comments from customers and utilities were taken into account to reach the present solution. This new metal-clad medium voltage arc resistant switchgear range has now been developed with these “best practices” and meets not only the requirements of ANSI and IEC, but will also fulfil the specific standards of different other nations all over the continents including those of China, Australia, and South America).

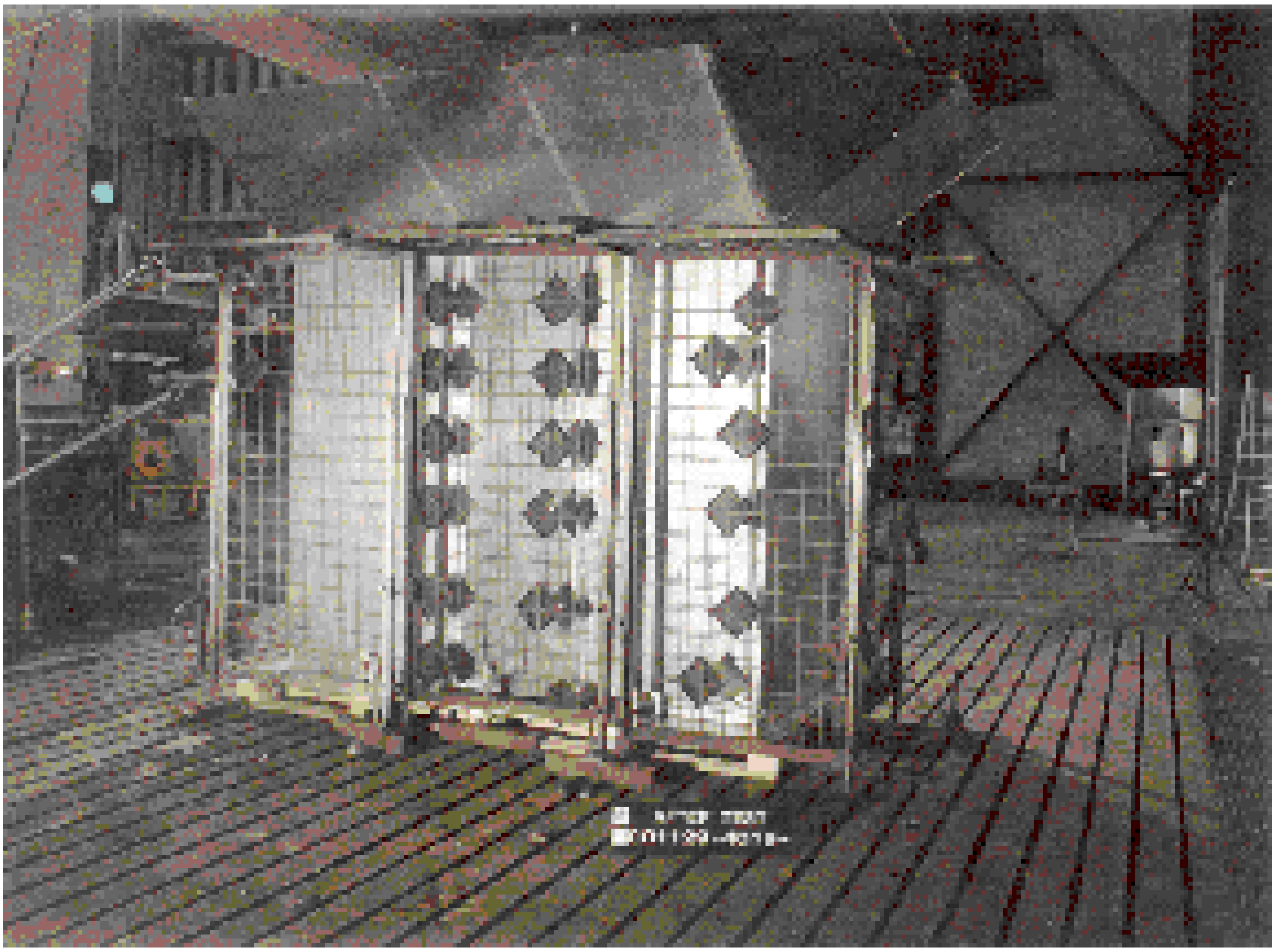


Figure 1. Panel after internal arc test at test station.

5. Tests

Tests have been performed at independent laboratories considering the different aspects of the product and the different demands of the standards. Care has to be taken in the choice of functional unit and test arrangement in order to cover the different and most difficult cases of applications. Thus cubicles not only at the extremities of a panel but also for application in the middle of a panel were tested. Importantly, the majority of the tests were carried out for a full one second internal fault. Similarly tests were carried out on all compartments separately, and the design evolved using a combination of modelling and empirical testing until satisfactory results were obtained.

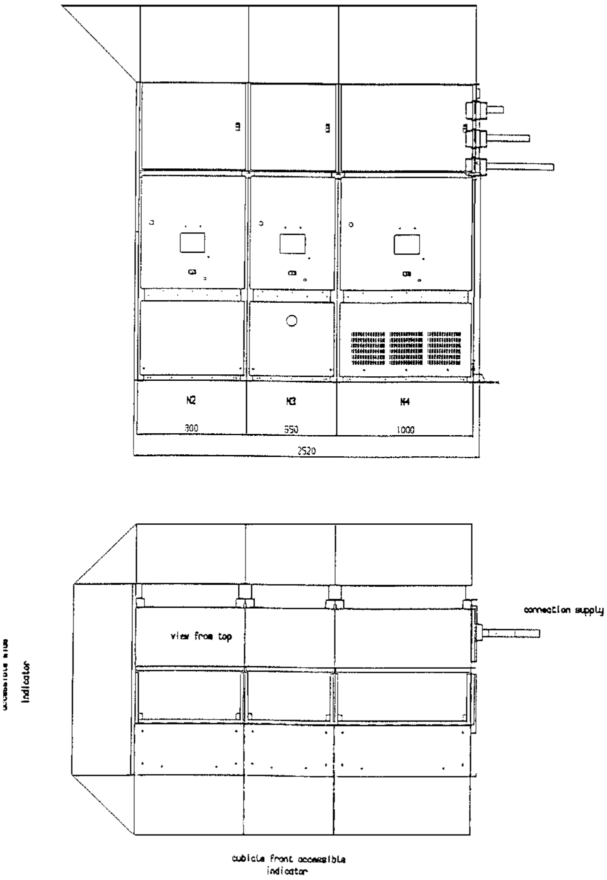


Figure 2.

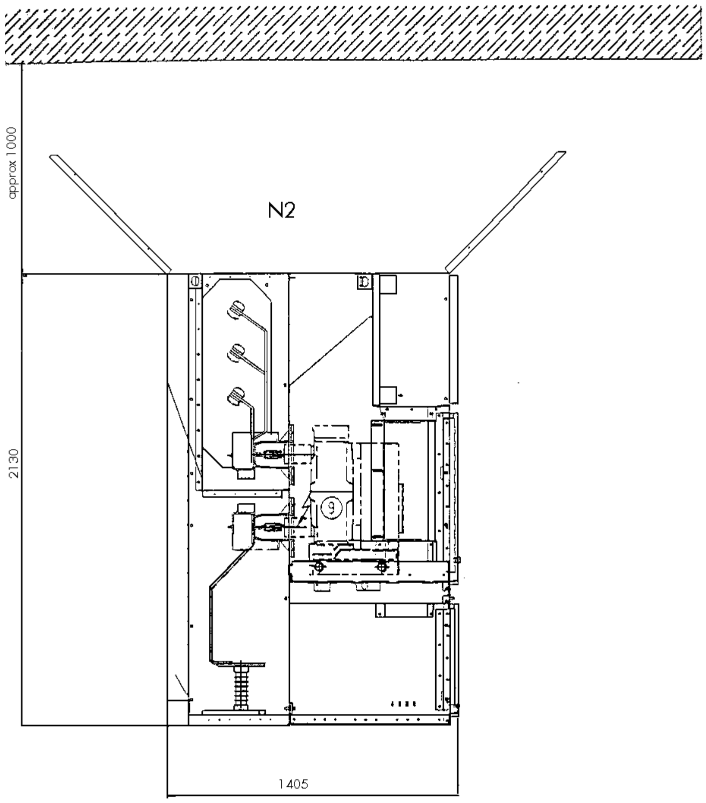
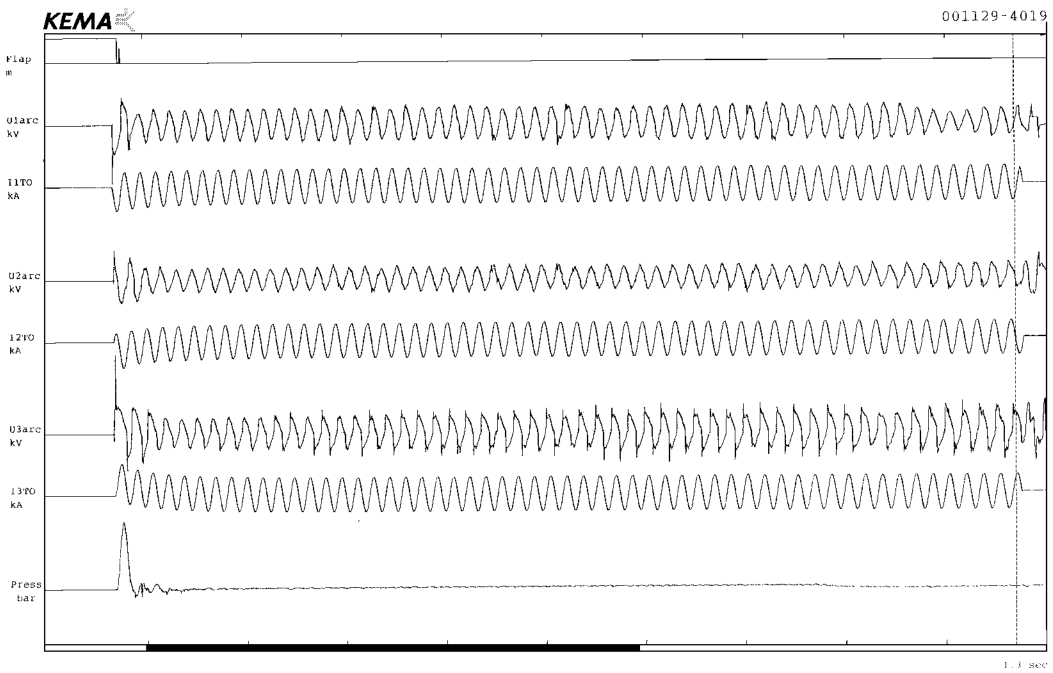


Figure 3.

A typical test arrangement is shown in Figures 1, 2, & 3, where the test object consists of 3 cubicles. A test in the circuit breaker compartment with an arc fault current of 40 kA/1s was carried out in the end cubicle with accessibility on front, left side and rear. The test arrangement in the photo (Figure 1) shows the equipment immediately after the test, with all of the indicators intact (the black squares of cloth next to the panel).

The oscillogram (Figure 4) of the 3 phase arc fault test 40 kA / 1s shows arc currents and arc voltages in all the three phases, together with pressure as a function of time (bottom trace). The instant of opening of the pressure relief flap can be clearly seen. The energy developed during the test measured 38 MJ.



It is important to note that the results of the tests will be representative of real life of the product only in so far as the conditions of installation asked by the manufacturer are respected. As stated below, good documentation is very important to prepare an installation to comply with this requirement.

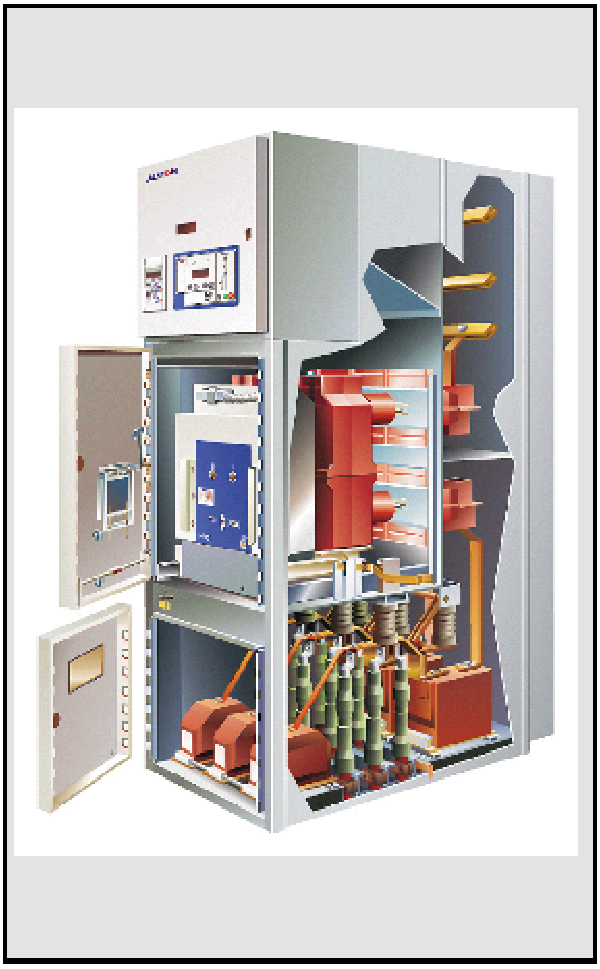


Figure 5. Internal Arc resistant MV switchgear Design.

6. Features of an internal arc resistant switchgear :

(Features of importance to have a successful design)

1. Doors and front covers:
Special measures are taken to design these parts to be able to withstand severe stresses. After closing they should slide laterally into position to enable a larger fixing surface.

2. Rear wall :
This is to be designed in such a way that it allows pre-determined deformation to take care of the high stresses in the cable compartment without bursting. Its strength and design should permit back to wall or installation with a rear corridor.

3. Pressure relief flaps:
These are to be designed to allow early pressure relief (within approximately 10 ms of occurrence of a fault) to avoid any mechanical bursting of the corresponding compartment. They are to be light in weight and are to be fixed properly so that they cannot fly off while opening under pressure.

4. Position of pressure relief flaps:
The position of flaps is to be so designed that the opening of the flap may take place within the overall dimension of the cubicle. Thus no consideration is required during installation regarding rear wall or ceiling. This gives an extra advantage to keep the height of ceiling or the distance to wall to a minimum

5. Flaps to close air ventilation openings:
In case there are ventilation openings they should be equipped with closing flaps to be able to close the ventilation openings immediately after occurrence of an arc fault

6. Segregated busbar compartment:
Busbar compartment is to be of segregated type (i.e., separation between neighbouring busbar compartments).This has the advantage that the fault in busbar remains confined in the place of origin.

7. Spouts and insulating materials used
These are to be selected carefully not to produce any exotic gases when subjected to internal arc and they should possess flame resistant characteristics.

8. Special measures for higher arc fault current:
Use of additional pressure relief in the cable compartment, use of additional sheet metal in the partition wall, and use of extra light-weight pressure relief flaps help to withstand higher arc faults.

9. Separating space between two adjacent cubicles:
While designing die side frame care should be taken in such a way that when assembled in rows side by side there should be a free space of about 5 mm left between the side walls of two adjacent cubicles. This gives an extra security for the neighbouring cubicle. If penetration by the arc takes place in the faulted cubicle the neighbouring cubicle is not affected and remains intact. One other advantage of this design is that there is a minimum of interference between a faulted cubicle and those on each side when extracting it to repair. This greatly speeds up any maintenance or repair time.

10. Separate cable canal for low voltage wiring:
The cable channel should be concealed within a protected sheet steel enclosure which gives extra protection against the effects of thermal overloading caused by the very high temperature arising from internal arc in the compartment. This provides extra security for the monitoring and controlling instruments in the low voltage compartment.

11. Inspection windows:
Inspection windows are necessary as they allow a visual control of the position of the withdrawable part and position of the earthing switch and cable lugs , which can prevent in some cases an internal arc fault due to maloperation or ageing. They are to be specially designed and located in frames inside door or front cover. The bending of the door or front cover due to high pressure during arc fault is not transmitted to the frame of inspection window and thus protects the glass from bending stresses.

12. Blastshields:
These are to be designed to retain the hot gases as well as the molten materials within the near vicinity of the installed equipment so as not to endanger the operating personnel.

7. Conclusion:

With today's high development standard of medium voltage substation equipments and the improvements implied in the design, the possibility of occurrence of an internal fault is very remote. However if this still occurs, then the consequences of an internal fault can be considerable, both from a hazard and an operational point of view.

Nevertheless, in case an internal fault still happens, it has been demonstrated above that, by careful design, the effects of internal arc fault and the shut-down time can be reduced to an absolute minimum. Arc resistant switchgear is now well defined by the standards and available on the market.

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Annex:

Comparison of the main points of IEC and ANSI regarding internal arc;

IEC62271-200	IEEE C37.20.7
Accessibility Two classes defined with identification of front, lateral or rear side Class A: restricted to authorised personnel Class B: unrestricted	**Accessibility** Three classes are defined, 1) at freely accessible front and 2) at freely accessible exterior (front, back and sides). 3) for equipment designed to compartmentalise components
How the test object is to be equipped, how test specimen is to be chosen The specimen shall be fully equipped , mock-ups of internal components are permitted provided they have the same volume and external material as original item Each compartment of a functional unit shall be tested. In case of modular functional units, the test specimen shall consist of 2 functional units connected together as in service. When there is a substantial difference in strength between the joining sides of adjacent units and the side forming the end of the switchboard, 3 functional units shall be used and the test of different compartments repeated in central and lateral positions.	**How the test object is to be equipped, how test specimen is to be chosen:** Same as in column 1 Any opening created in the equipment as a result of manufacturing, assembly or modification that have an intentional covering, may have that covering installed. Openings without intentional coverings may not be blocked for the test. Each variation in bus phase spacing and clearance to ground should be tested, except for configurations where only the size and/or the quantity of bus changes. In these configurations, a representative enclosure may be tested using the smallest physical bus size to produce the greatest phase to phase and phase to ground clearances. A typical section may be used to perform the test provided its compartment represent the smallest internal volume and/or most restrictive method for relief of overpressure.
Room simulation The room shall be represented by a floor, ceiling and 2 walls perpendicular to each other and exhaust ducts simulated cable access.	**Room simulation** The test arrangement should simulate room conditions in a manner that consider the following: -distance to adjacent walls

Unless manufacturer states a larger minimum clearance, the ceiling shall be located at a distance of 500 mm from the upper part of the test specimen. The lateral and rear wall shall be placed at 100 mm from the lateral and rear side of the test specimen in case of non accessible lateral or rear side. For accessibility of rear and lateral sides the walls shall be placed at a distance of 800 mm If the design is with exhaust duct the tests shall be performed with simulation of such exhaust ducts.	-ceiling height -any obstruction located near the equipment that may deflect hot gas into an area defined by the accessibility type -any opening beneath the equipment (cable vaults) which may allow hot gas to escape into an area defined by the accessibility type. If the design incorporates an exhaust system that will vent pressure directly out of the room, no room simulation is necessary.
Indicators These are pieces of black cotton clothes (150g/m^2 so arranged that their cut edges do not point toward the test specimen. Care shall be taken to see that they can not ignite each other. Indicators shall be fitted at all accessible sides of the metal unit vertically up to a height of 2 m. The distance from the indicators to the switchgear shall be 30 cm.(for class A) and 10 cm (for class B). Indicators shall also be placed horizontally at a height of 2m above the floor on all accessible sides between 30 and 80 cm (accessibility A) or between 10 and 80 cm (accessibility B) from the unit. When ceiling is placed at a height of 2m above the floor, no horizontal indicator is needed. The length of mounting frame shall be bigger than the test specimen to take into account the possibility of hot gases escaping in slant direction (up to 45°). The area occupied by the indicators shall be at least 50% of the global area reserved to the indicators positioning.	**Indicators** Indicators are pieces of black cotton cloth (150g/m^2) so arranged that their cut edges are not exposed to the test sample and each indicator is isolated from each other to prevent multiple ignitions from a single source. This is obtained by fitting them in a special mounting frame. Vertical indicators are to be located from floor to a minimum height of 2m and at a distance of 100 mm from the switchgear. If the equipment is intended for mounting on an elevated base, indicators should be placed below the base of the test sample to monitor gas escape at the floor level. Horizontal indicators are to be located at a minimum height of 2m from the floor and horizontally 0.8m from the sample. The internally mounted indicators for accessibility type 3 are to be located at 100 mm from the interior surface being evaluated. Internal indicators are mounted in any applicable plane, parallel to the surface being evaluated. There is no height restriction for internally mounted indicators. They should be mounted for the applicable surfaces up to full height of the equipment.
Test connection The test should be carried out 3 phase. The short circuit current applied during the test may be lower, if specified by the manufacturer, than the rated short time current withstand. A lower voltage than the rated may be applied if the following conditions are met: -the current remains practically sinusoidal -the arc is not extinguished prematurely The specified short circuit current should be set within +5% -0% tolerance. This tolerance applies to the prospective current only if the applied voltage is equal to the rated voltage. The current should remain constant. Frequency deviation is between 48-62 Hz for a rated frequency of 50/60 Hz For a rated frequency different from 50/60 Hz, the frequency at the beginning of the test should not deviate from the rated value by more than 10%	**Test connection** The tests should be carried out 3 phase. If a lower voltage is applied it should not be less than 60% of the rated voltage and is not recommended for equipment rated 5 kV and below. The maximum value of the AC component during the test shall not exceed the minimum value of the ac component during the test by more than 15% Where fast active protective devices will limit the rated duration of test arc to 50 ms or less, the frequency at the beginning of the test shall be rated frequency of the equipment ±10%. For a rated duration greater than 50 ms, the frequency at the beginning of the test shall be the rated frequency of the equipment ±20%and the frequency of waveform should not deviate from the initial value by more than 8% for the duration of the test.
Duration of arc fault Standard recommendations are 1 sec, 0.5 sec and 1 sec	**Duration of arc fault** Preferred value 0.5 sec
Criteria to fulfil a test IAC 1 class switchgear is qualified if following criteria are fulfilled : No 1 whether correctly secured doors, covers do	**Criteria to fulfil a test** For qualification as arc resistant switchgear followling conditions are to be met: No 1 secured doors, do not open. Bowing or other

not open. Deformations are accepted provided that no part come as far as the position of the indicators or the walls in every side. It is admitted that the switchgear does not comply anymore with its IP code No 2 whether no fragmentation of the enclosure occurs within the time specified for the test. Projection of small parts (upto 60g) are accepted provided they stay within the position of the indicators. No 3 arcing does not cause holes in the accessible sides upto a height of 2 m No 4 indicators don't ignite due to the effect of hot gases No 5 whether all earthing connections are still effective	distortion is permitted except on doors, covers which may have devices (relays). No sign of distortion which could cause these devices to be ejected from the equipment is acceptable. No 2 Parts are not ejected in the vertical plane defined by the accessibility type- Parts large enough to be hazardous do not eject from top of equipment. No 3 assessment of burn-through -accessibility type 1 arcing does not cause holes in the freely accessible front of the enclosure -accessibility type 2 arcing does not cause holes in the freely accessible front, sides and rear of the enclosure -accessibility type 3 arcing doesn't cause holes in the freely accessible front, sides and rear of the enclosure or in the walls separating the vertical sections in an assembly or between compartments of a vertical section No 4 indicators do not ignite as a result of escaping gases or particles. No 5 whether all earthing connections are still effective.