



Effect of Roof Height on Internal Arc Testing of Switchgear Panels

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Abstract

The market requirements for Medium Voltage (MV) metal enclosed switchgear are getting more and more stringent. Both building costs as well as the level of the transmitted and distributed electrical power have increased rapidly over the recent years and are expected to continue to rise. This means that switchgear manufacturers must bring more and more compact and powerful systems on the market, while being simultaneously as cost effective as possible. Internal Arc Classification (IAC) of switchgear according to IEC and IEEE standards is one of the most important requirements to guarantee safety in case of internal arc faults. Internal arcs cause a sudden pressure rise in electrical installations. This leads to an extreme pressure stress acting on switchgear compartments and switchgear rooms and could cause collapse of buildings. This paper describes few important design rules and innovations, which were necessary to achieve best results during internal arc tests. Furthermore it demonstrates the effect of roof height during the internal arc test with the important case studies. Finally the best solution to eliminate the roof effect is also proposed.

Keywords: High Speed Videography Analysis, IEC 62271-200 and IEEE C37.20.7, Internal Arc Test, Roof Height, Switch Gear Panel

1. Introduction

Internal Arc faults in medium voltage switchgear are today relatively rare events (for example: about 2 incidents per week in Germany). However, the potential effects of an internal arc represent a massive hazard to operating personnel, electrical equipment, buildings and public. During such a high current event, up to 70MJ of electrical energy can be dissipated in the apparatus within a mere 100 milliseconds causing a huge and fast transient overpressure and overheating (up to 30000K in the arc core and up to 1000K in the immediate environment of the failed compartment) into the environment¹.

The next effect of internal arc is a more or less significant expulsion of hot gases, flames, fumes and glowing particles which can also endanger humans and equipment. This pressure rise results in mechanical forces acting on walls, roof of the building which may lead to collapse of the building.

The causes of arc faults start with errors and/ or deficiencies in the planning and coordination of use cases. They are caused also by product defects, poor

environmental conditions as well as errors in the operation, but mostly human errors and inadequate maintenance. The standards (IEC 62271-200 and IEEE C37.20.7) for MV switchgear give clear and comprehensive information and recommendations of the appropriate measures to prevent Internal arc faults and to limit their impact if they happen. A consistent implementation of these measures and the quality assurance in the planning/ design, manufacturing, installation and commissioning as well as during operation do minimize the risk of internal arc considerably.

Generally, MV-switchgears have to be designed based on the following objectives:

- Maximum performance
- Maximum operational reliability
- Maximum personnel safety
- Minimum footprint
- Minimum maintenance
- Minimum manufacturing costs for the entire product range
- Modular and cost-effective assembly

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- Independence of environmental impacts such as condensation, atmospheric pressure, dust, fumes, gases, small animals, oxidation.

The market requirements in terms of IA fault protection differ in the degree of accessibility (AFL: front and lateral accessibility of operating personnel and AFLR: front, lateral and rear accessibility of operating personnel) and the type of the Pressure release system (Pressure release into the installation room or pressure release into the atmosphere) In order to optimize manufacturing costs the dimensions of the switchgear units need normally to be adapted to the required current ratings. This increases the number of product variants for a given type of switchgear. For example, the new gas insulated switchgear type was divided into four variants 450mm/ 600mm/ 800mm and 1000mm according to the current ratings 800A/1250A/2500A and 2500ABus Section. Furthermore, considering the possible required short-circuit and voltage ratings on the MV switchgear market, the variability of a same switchgear type may rise to an unacceptable level from economical and manufacturing points of view.

All necessary design features of the different parts and components of this core unit and the key technical challenges and issues of the qualification campaign can be summarized by the following questions:

- How to stabilize the high current arc in order to protect the enclosure against burning through as well as to reduce the dissipated arc energy?
- How to reduce or prevent completely the ejection of hot gases and glowing particles in the installation room during an Internal arc fault while maintaining the thermal performance of the switchgear during normal service at rated currents?
- How can doors be secured and sealed for the required IAC, preferably without additional screws or parts which necessitate a use of additional tools for the customer?
- How to dimension and install pressure release systems (disks, flaps etc...) to achieve an optimal behaviour (controlled evacuation of hot gases) during an Internal arc fault?
- How to ease user maintenance and operation
- More generally, how to reduce production costs ?

In some installations however, gases are released into the switchgear room. This induces a pressure rise in the

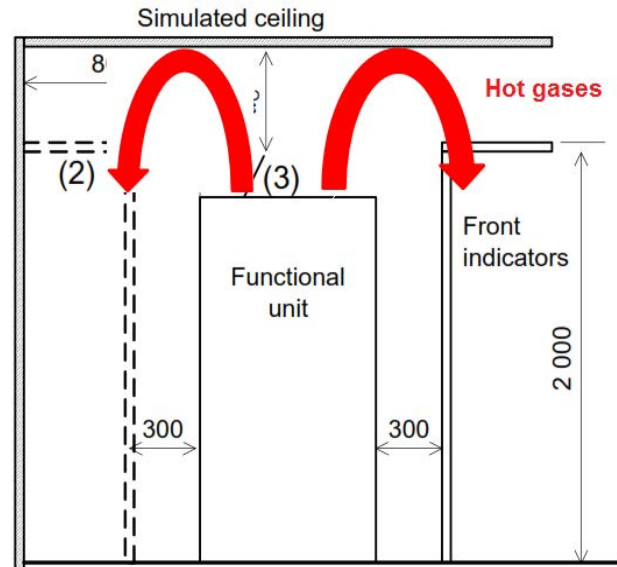


Figure 1. Gas flow during internal arc test.

room, thus a mechanical stress of the building itself. With this rise in pressure the gasses will return back to the operator standing in the vicinity of the panel as shown in Figure 1. The effect these gasses on the operator are purely dependent on the height of the roof from the panel top. The effect of these gasses on the people can be studied by conducting the actual test on the panel with the defined roof height.

2. Design Requirements of Metal Enclosed Switchgear¹²

Metal enclosed switchgear design must consider mainly internal arc fault, the effect of arc restricts in arc place, to ensure normal operation of other functions that has nothing to do with the failure. High-speed relay and monitoring system of arc is conducive to found the fault to ensure that the power outage and the change time down to the minimum.

In order to meet the requirements of different standards, switch equipment should take special measures for each compartment of different functions. Especially the cupboard door and the design of the front cover should be tolerated serious force and not to impact external. Moreover, also should pay attention to the design of circuit breaker and the bus compartment pressure relief device, that can't pollution bus compartment when the circuit breaker compartment pressure relief devices to open. The circuit breaker room interval can't

pollution when open safety pressure relief devices of bus compartment. In addition, some measures should be taken to prevent burning through and make sure to hit parts of the security. In addition, it is important to pay special attention to the requirement of the observation window to make sure that can't let the device a component or a piece of something go out with the failure. These new designs are fit for the situation that have channel on the front, rear or side according to the requirements.

Therefore, the following measures should be taken to avoid the happening of internal arc fault or lower damage degree of internal arc from two aspects of the electrical and mechanical design in the process of design and operation.

2.1 Electrical Design

Because the energy size of the arc fault is determined by the current and its duration, so in the following some electric method can reduce the damage degree of the fault.

- a. Impedance grounding system. It is effective for fault between phase and ground. Single phase grounding fault arc often turn into two phase and then be to a three-phase short circuit fault arc, the impedance grounding system can reduce the incidence of single-phase grounding fault arc.
- b. Fast differential relay protection and breaking. One of the most effective way of reducing the arc fault and releasing energy is to shorten the arc burning time. Total time is about 70–100 ms by using fast differential relay and new type circuit breaker.
- c. Detection and breaking of ground fault current.
- d. Undamaged insulation system, medium voltage switchgear can reduce the incidence of arc fault by using insulated bus bar. Because if the arc fault occurs, the undamaged insulation bus bar can make fault evolved into three-phase arc fault.
- e. Light, sound, pressure testing. Light, sound, pressure, and accompanied by current rising rapidly, which is the signal of switch cabinet internal arc fault. Some of these phenomenons can be observed, and can be detected in dozens of milliseconds after the occurrence of fault. The consequence can be obtained through internal arc fault detection protection device consist optical fiber sensor and fault analysis unit of [4-11](#).

- f. Using fast sub switch. Quick short switch quick close after arc fault happens to make the arc fault into three phase short circuit current, and make the upstream brake switch opens to achieve the goal of quick extinguishing arc.
- g. Using current limiting fuse or breaker. Reduce the arc energy.
- h. Monitoring partial discharge. Monitor partial discharge of the switchgear insulation system through on-line monitoring technology when switch equipment runs to determine whether there is a potential problem. That predicts if failure will happen by analyzing the change trend of discharge with time so as to take measures to eliminate hidden dangers.
- i. Cable should be into line or out-line below, which makes pressure relief devices in the top of the cupboard free to open, hot gas caused by arc can be discharge smoothly.

2.2 Mechanical Design

Switch equipment should be design and installation in accordance with the standard. In addition, the correct mechanical design can reduce the damage caused by arc fault. Need to pay attention to the following part of the design and the function and characteristics of each part are described below.

- a. **Interlocking:** effective interlock can prevent wrong operation, prevent people from entering the charged interval. Interlock is very important, the reasons are: Operating frequency very few, so operators has limited operating experience. Distribution switchgear is variety and operating is in a different way. Operations tend to be happened when power grid failure occurs and the operator must be rapid processing. But then the high perator pressure, tension and operating environment is poor, such as the light is dark, the night, a rainy day.
- b. **Insulation and isolation room:** bus insulation and a variety of high-pressure compartment method is very effective to prevent the arc faults occur. These techniques reduces greatly the chance of contact with live parts accident, also limits the possibility of arc fault. So, as far as possible make all conductors insulate, especially small busbar system and switch small room

which cause often fault because of pollution. In addition, all high voltage isolation room should use highly complete seal, in order to avoid burning gas diffusion during the fault.

- c. **Equipment isolation:** because of the high voltage equipment usually has been charged, so make sure people safe effective method is to isolate. Measures are that use a barrier for outdoor equipment or close the door for indoor equipment and only the operator can enter.
- d. **Remote operations:** using remote control method to achieve the purpose of operating personnel away from the high voltage equipment.
- e. **Using guide device:** hot gas will be leaded to the safe zone by this device.
- f. **Pressure relief devices:** release should have sufficient strength and not subject to accidental damage or deformation, reliable operation, which can be opened freely and flexibly.
- g. **Gas cooling device:** this device can make the gas cooling rapidly. Ultimate goal of such design is to ensure substation personnel as secure as possible. The results show that this design has reached the high level after completion of the internal arc test in the laboratory.

3. Standard³

The internal arc test, as a mandatory type test, is intended to verify the effectiveness of the design in protecting persons in case of an internal arc and is defined in internal arc class (IAC). This class is intended to ensure a tested level of protection to persons in the vicinity of the electrical equipment in normal operating conditions and with the switchgear and control gear in normal service position. The internal arc class makes allowance for internal over pressure acting on covers, doors, etc., and it also takes into consideration the thermal effects of arc or its roots on the enclosure and of ejected hot gases and glowing particles. The definition of internal arc classes (IAC) describes mainly the types of accessibility, test arrangement, test procedure and acceptance criteria.

The types of accessibility A, B (for authorized personnel only and general public, respectively) and type C for pole mounted metal enclosed switchgear. The accessibility of type C is restricted to installation out of reach. The accessibility of type A and B is defined more

precise, by defining different sides of the enclosure as front (F), lateral (L) and rear (R) side. The test arrangement shall include fully equipped test objects. Mock-ups of internal components are permitted with the same volume and external material as the original items and with no influence on the main and earthing circuit. The test shall be performed in every compartment of the switchgear and control gear containing main circuits. Extensible modular units shall be tested in all compartments at the end of a minimum arrangement of two units. All the tests shall be done on representative functional units. In the case of fluid-filled compartments, other than SF₆ (sulfur hexafluoride), the test shall be made with the original fluid at its rated filling conditions.

The room simulation and the arrangement of the test object are clearly defined; the room shall be represented by a floor, a ceiling, and two walls perpendicular to each other. The minimum distance between the ceiling and the upper part of the switchgear and control gear shall be 200mm ± 50mm, Respectively the minimum height of the ceiling shall be 2000mm ± 50mm from the floor for test objects with a height of less than 1800 mm. manufacturer can declare the height of the ceiling from the ground. For lower clearances to the ceiling, the manufacturer may carry out an additional test.

The lateral wall shall be placed at 100 mm ± 30 mm from the lateral side of the test specimen. The manufacturer may carry out an additional test with higher clearances to the lateral wall, in order to assess the criteria for installation conditions. From the technical view, testing with a minimum distance of 100 mm fulfills the criteria. The pressure stress outside the switchgear compartment is related to the volume, which is available for expansion.

The definition of the rear wall depends on the type of accessibility. The distance from the wall for non-accessible side is to be maintained at 100mm ± 50mm and for accessible side the distance to be maintained at 800mm ± 50mm. The use of exhaust ducts to guide generated hot gases during the internal arc test, shall be tested with the minimum cross-section dimensions, location and output features of the ducts, like flaps or grid. The output end of the exhausting ducts shall be at least 2000 mm away from the tested switchgear and control gear. An additional remark on security of the personal protection near the output is missing. A definition for hot gas flow directions into the surrounding with respect to personal safety can be helpful.

The material, fixation, and arrangement of the indicators are defined in detail to assess the thermal effect of the gases. The indicators shall be placed on a mounting rack at each accessible side at distances depending on the type of accessibility. To simulate the position and work clothes of authorised operators (accessibility type A) the distance of indicators to switchgear and control gear shall be 300 mm \pm 15 mm. Indicators shall be fitted vertically at all accessible sides up to a height of 2000 mm, arranged in a checkerboard pattern so that 40 - 50 % of the area is covered. The horizontal indicators shall be arranged to a height of 2000 mm above the floor and covering the whole area between 300 mm and 800 mm from the test object; when the ceiling is placed at a height of 2000 mm above the floor, no horizontal indicators are necessary. The arrangement of the horizontal indicators shall be in the same way as the vertical ones. The arrangement of accessibility type B shall be assessed against the consequence of an internal arc fault for the general public.

The main difference between accessibility type A and B is the reduction of the distance between the vertical and horizontal indicators and the enclosure to 100 mm \pm 5 mm. The horizontal indicators shall be arranged to a height of 2000 mm above the floor and covering the whole area between 100 mm and 800 mm from the metal-enclosed switchgear and control gear. If the height of the test object is lower than 2000 mm, vertical and horizontal indicators shall be placed at a distance of 100 mm \pm 5 mm higher respectively direct on the top cover. The internal arc test shall be carried out three-phase for three-phase systems. The short-circuit current applied during the test corresponds to the rated short-time withstand current. It may be lower if specified by the manufacturer. The value of the peak current shall be 2.5 times of the rated current for frequencies up to 50 Hz and 2.6 times for frequencies up to 60 Hz. The manufacturer shall define the duration of the test. Standard recommended values are 1 s, 0.5 s and 0.1 s.

The energy feeding direction is described in detail for each compartment of the switchgear and control gear. The arc initiation shall be done between all three phases or between one phase and earth of segregated phase conductors. The point of initiation in the compartment shall be located at the furthest accessible point from the supply, within the compartment under test. In case of segregated phase conductors, the arc ignition shall be between one phase and earth at gaps or joining surfaces between the insulation of insulation-embedded parts.

The initiation of the arc in a cable compartment shall be done between two phases at the plugs without insulation and the third phase shall be provided with a plug-in connector as can be used in service and able to be energised.

4. Internal Arc Testing

Table 1. Equipment rating of High power Laboratory for large power transformers

Equipment	Rating
SC Generator	Quantity: One Rated capacity: 2500MVA (50/60Hz) Rotation speed: 3000/3600rpm Nominal rated voltage: 14kV (Line to Line)
Short Circuit Transformer	Quantity: Three Rated Capacity: 1150 MVA Primary voltage: 14kV Secondary voltage: 42-42 kV No of phases: Single-phase

The internal arc testing will be carried out in High Power Laboratory. The main equipment's ratings of present High power Laboratory (HPL) for large power transformer testing are as shown in Table 1. In CPRI High Power Laboratory, Bangalore the internal arc test was carried out many switchgear assemblies up to 50kA.

In this paper two tests were presented with explain the high speed videography analysis to explain the importance of the roof height and its effect on the internal arc test.

One, on 12 kV, 1250 A, 25 kA Indoor Metal Clad Vacuum Switchgear, whose details are given in Table 2 and another on the 36kV 1500 A, 26.3 kA Indoor Metal Clad Vacuum Switchgear, whose details are given in Table 3.

Table 2. Equipment rating of vaccum switch gear

Rated Voltage	12 kV
Rated current	1250 A
IAC rating	25kA for 1.0 sec
Number of Phases	3
Class	Indoor
Accessibility	AFLR
Test as per	IEC 62271-200

Table 3. Equipment rating of Indoor Metal Clad Vacuum Switchgear

36 kV	Rated Voltage
1500 A	Rated current
26.3kA for 1.0 sec	IAC rating
3	Number of Phases
Indoor	Class
AFLR	Accessibility
IEC 62271-200	Test as per



Figure 2. 12kV switchgear panel mounting arrangement.



Figure 3. 36kV switchgear panel mounting arrangement.

The mounting arrangements for these equipment are shown in Figures 2 and 3. The positioning of the indicators is shown for different types of the mountings. In Figure 2 the indoor switchgear panel is mounted in the room simulation with the roof height of 2.5 meters from the top of the panel. The condition of the indicator after the test is shown in Figure 4. From the Figure 4(a) it is very clear that the vertical indicator cloths placed around the panel is found intact, but the horizontal indicator cloths placed on the top of the rack are found burnt due to the hot gases, which is clearly shown in Figure 4(b). From this it is very clear that even though the panel is made very strong, such that no hot gases escape through the panel on the accessible side, still the switchgear panel failed to clear the test because it is not designed to release the hot gases for the designated height of the room.

In Figure 3 the indoor switchgear panel is mounded with the minimum roof height prescribed in the standard, which is 600mm. during the test the top pressure relief is not functioned properly and the hot gases make their way to the roof by opening the cover on the top side.



(a)



(b)

Figure 4. Condition of the indicators after test.



Figure 5. Condition of the indicators after test.

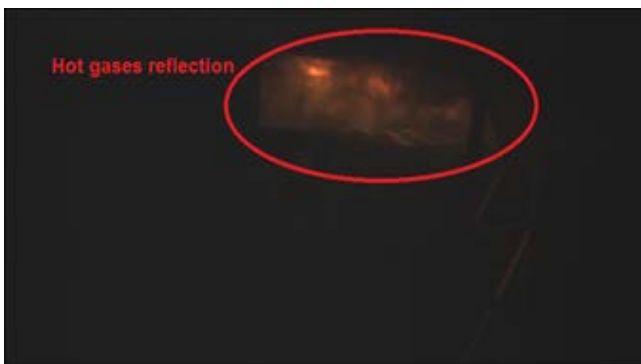


Figure 6. The reflection of hot gases captured in high speed video graphy.

These hot cases went up and hit the roof and the reflected gases burnt the horizontal indicators, which is shown in Figure 5. The path of reflected hot gases is shown in Figure 6, which is captured using high speed videography. The oscillographic recordings are shown in Figure 7.

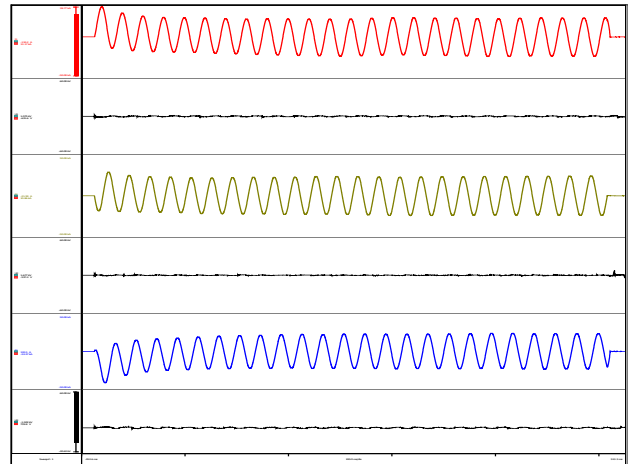


Figure 7. 36kV current and voltage recording.

5. Conclusion

Switchgear assemblies have to comply to internal arc classification with the relevant international standards. The personal safety with respect to internal arc protection is one of the most challenging design criteria. The effect of the roof simulation on the personal safety is one of the most important phenomenons, which is clearly presented in this paper. From the case studies it is very clear that even though the diverters were used, if the roof height is not selected properly the adverse effects can't be overruled.

The author is of the opinion that the use of absorbers decreases the overpressure in the switchgear room significantly. Furthermore, the exhaust of hot gases and glowing particles is reduced in comparison to the use of deflectors. The flow resistance depends on the topology of absorbers. By streaming through the absorber, the kinetic energy of the gas decreases due to the friction forces and turbulences. The effective open cross section of the pressure relief is also reduced due to the absorber. Both properties reduce the pressure stress behind the absorber significantly, which is shown in Figure 8.



Figure 8. Absorber.

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