INTERNAL ARC TESTING OF MEDIUM VOLTAGE SWITCHGEAR - EXPERIENCES WITH IEC 62271-200

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SUMMARY

The international market of air- and gas-insulated switchgear for electrical transmission and distribution demands high requirements with respect to reliability of operation and safety. Despite the continuous optimisation of electrical switchgear and controlgear it is unavoidable, that failures may occur during operation. The probability of the occurrence of an internal arc in metal-enclosed medium voltage switchgear during its entire service lifetime is rather low but it cannot be completely disregarded.

To increase safety for operators and general public in case of an internal fault, the international standard for medium voltage switchgear includes internal arc test as a mandatory type test where applicable. The IEC 62271-200 [1]"AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV" was official implemented in November 2003. The revision of IEC 60298 [2] (December 1990) included several changes, especially for the test arrangements and procedures [3]. The type tests comprise an internal arc test on a representative functional unit in every compartment containing main circuit parts. The types of accessibility A and B (for authorized personnel only and general public respectively) are extended to include type C for pole mounted metal-enclosed switchgear. The protection level relative to the five acceptance criteria and relevant accessibility type are defined by an internal arc classification (IAC) for the front (F), lateral (L) and rear (R) sides of the switchgear. In this context the test arrangement is defined more precisely, especially for room simulation of indoor applications.

The IEC 62271-200 imposes stringent requirements for the design of medium voltage switchgear. The experiences with internal arc test according to the latest standard are described at the example of a new developed gas-insulated switchgear generation for primary distribution. All tests were successful done for internal arc class IAC AFL / AFLR and a short-circuit current up to 40 kA with a test duration of 1 s [4]. The test arrangements and results were shown on single and double busbar system.

The development of the gas insulated switchgear under technical and economical constraints required the enforced employment of simulation tools. The efficiency of the various design concepts, relative to an internal fault, was assessed by the results of 3-dimensional numerical calculations. The simulation results are compared with measured data of internal arc test.

The comparison of individual requirements of national and international users, utilities and industries, and the definitions of IEC-standard for internal arc test were presented and discussed.

INTRODUCTION

Medium voltage air- and gas-insulated switchgear for electrical transmission and distribution are designed and tested in accordance to national and international standards to guarantee high reliability of operation and safety. Manufacturers of electrical switchgear develop, in a continuous dialog with the end user, the plant components under the technical and economic requirements, whilst respecting the national and international specifications and test requirements. The defined type and routine tests relative to the mechanical, dielectric, thermal and other requirements guarantee a long-term safe operational record. Despite the constant optimisation of electrical switchgear and controlgear it is unavoidable that disturbances occur in operation.

The probability of the occurrence of an internal arc in metal-enclosed medium voltage switchgear during its entire service life is very low but it can not be completely disregarded. The main causes of an internal arc are:

- Operational and maintenance faults
- Atmospheric and switching over voltages
- Dielectric faults of solid insulation materials (e.g. cable terminations, voltage and current transformers)
- Overstress of load break switches, circuit breakers or fuses

The internal arc heats directly the surrounding insulation gas and a part of the electrical energy will be transferred via convection and heat conduction in thermal energy, which results in an overpressure in the switchgear compartment. After exceeding a predetermined pressure limit, the hot gases expand over pressure relief devices into the substation or switchgear building. The hot gases and the transient pressure waves may endanger persons in the switchgear room and may seriously damage the electrical equipment and the building. One of the main effects of internal arcs is the dynamic pressure stress on mechanical parts of the switchgear and on the walls of the building. To avoid the destruction of the substation or the switchgear building it is necessary to integrate overpressure relief systems in form of ventilation openings, vent outlets etc. Besides the mechanical stress to equipment, the danger to persons close to the switchgear must be excluded. The safety of operators against hot gases, radiation and fragmentation of the enclosure must be secured. The five acceptance criteria must be fulfilled for a successful internal arc test; e.g. correctly secured doors and covers do not open or indicators do not ignite due to the effects of hot gases. The internal arc safety to persons is proven by the manufacturer in representative switchgear according to IEC62271-200.

EXPERIENCES WITH IEC 62271-200 IN CASE OF INTERNAL ARC TESTING

The current valid international standard for metal-enclosed switchgear and controlgear for rated voltages from 1 kV and up to and including 52 kV is written in the first edition IEC 62271-200 from November 2003. The current standard is the result of the revision of IEC 60298 from December 1990 [3]. In 2006, the second edition of IEC 62271-200 was prepared by subcommittee SC17C and the project was assigned to maintenance team 14. The target date for the committee draft (CD) is proposed for June 2007, which will be followed one year later by committee draft for voting (CDV) in June 2008. The final draft international standard (FDIS) is foreseen in June 2009 and the date of publication as an international standard will be in December 2009.

The major change of IEC 62271-200, edition 1.0, is the revision of new definitions and classifications of equipment of metal-enclosed switchgear and controlgear. Other main modification are the introduction of internal arc classes (IAC) and the description of methods for testing. The qualification of a new design of a metal-enclosed switchgear and controlgear is done by several type tests.

The personal protection due to an internal fault in medium voltage metal-enclosed switchgear became in IEC 62271-200 a significant higher importance. 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 controlgear in normal service position. The internal arc class makes allowance for internal overpressure acting on covers, doors, etc., and it also takes into consideration the thermal effects of arc or it 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 and B (for authorised personnel only and general public, respectively) are extended to 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 controlgear 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 SF_6 (sulphur hexafluoride), the test shall be made with the original fluid at its rated filling conditions. The replacement of SF_6 with air is permitted, but the pressure rise will be different. The pressure will rise more rapidly in air, because of the difference heat capacities. Experimental results show that the maximum overpressure in air is always higher than in sulphur hexafluoride at same test conditions. For example, tests of a compartment with a gas volume of ca. 0,08 m^3 and a current of 31.5 kA showed an increase of the maximum pressure by 24 %. Therefore the mechanical stress of the metal-enclosed switchgear is for internal arc test in air higher than in SF_6 and guarantees maximum protection with respect to rupture and deformation of the tested compartment.

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 controlgear shall be 600 mm ± 100 mm. Respectively the minimum height of the ceiling shall be 2000 mm from the floor for test objects with a height of less than 1500 mm. For lower clearances to the ceiling, the manufacturer may carry out an additional test. In many cases, switchgear buildings or substations in utilities or industries are optimised also to minimum dimensions with respect to costs. Some users require very small building heights of less than 2500 mm, e.g. walkable compact substations and container. The standardised distance of 600 mm between the ceiling and the upper part of the switchgear, however, does not meet the technical requirements of the national and international market; a modification of this specification may be reasonable.

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 employment 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 al least 2000 mm away from the tested switchgear and controlgear. 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 controlgear shall be 300 mm ± 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 ± 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 controlgear. 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 ± 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 controlgear. 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.

The class designation of the tested switchgear and controlgear shall be included to the nameplate, e.g.:

Class IAC AFLR
Internal arc: 40 kA 1 s

The example describes a qualified metal-enclosed switchgear and controlgear according to the IAC class. The accessibility type is A for authorised personnel only on the front, lateral and rear side; the short-circuit current is 40 kA and the test duration is 1 s.

The defined internal arc test does not consider all effects of an internal fault. For example the dynamic mechanical stress on the walls of the switchgear room or building due to the overpressure is not considered. The standard does not provide rules how to calculate the effect of the overpressure when the hot gases will rupture over pressure relief devices inside the switchgear room or building. It is only written, that it should be taken into consideration when designing the installation.

The IEC62271-200 enforces high requirements for the design of metal-enclosed medium voltage switchgear and controlgear. The end user of such qualified switchgear and controlgear can be sure that the protection against an internal fault for the operator and for the general public is very high.

DEVELOPMENT OF A NEW GIS GENERATION ACCORDING TO IEC62271-200 WITH RESPECT TO INTERNAL ARC TYPE TESTS

The following chapter describes the development of a new gas-insulated switchgear generation GHA [4] for primary distribution for internal arc testing according to IEC 62271-200. All tests were successful passed for internal arc class IAC AFL / AFLR and a short-circuit current up to 40 kA (104 kA peak) with a test duration of 1 s.

The metal-enclosed gas insulated switchgear GHA is performed in a compact modular design with the possibility of extensibility on both sides. The rated voltage is up to 40.5 kV and a rated current up to 2500 A; the busbar system is available in single (SBB) and double busbar (DBB). Fig. 1 presents the switchgear and controlgear GHA with circuit breaker (vacuum interrupter), outer coin cable connection and double busbar.

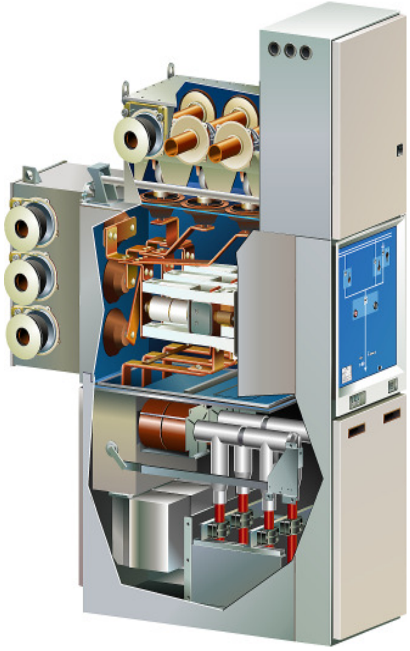

Fig. 1: Gas insulated switchgear GHA, 40.5 kV, 2500 A, 40 kA 3 s, Double busbar

The spatial and temporal distributions of pressure and temperature and fluid velocities, that result from an internal arc fault, are determining parameters for many aspects in the mechanical design. For that reason, various 3-D simulations of the arc test conditions were performed in the development process of the new AREVA product GHA.

Simulations and type tests were performed for a three-phase ignition with the rated short circuit current in the busbar compartment (iBB) and inside the circuit breaker compartment (iCB), and a two-phase ignition with 87 % of the rated current between two adjacent phases at the cables in the cable compartment (iCC). Here, simulation results for the iCC configuration are presented and are compared to the test measurement results.

When an internal arcing fault occurs, a lighting plasma arc forms a short circuit and an energy of many MJ is released within a second of time. Most of that energy is transferred to the insulation fluid, which is air in the case presented here. The air in the arc region is thereby heated up to temperatures of several thousand Kelvin within some milliseconds of time, causing the gas to expand explosively emitting a pressure wave. At these high temperatures, part of the energy is consumed by dissociation and ionisation of the gas molecules; another part of it is emitted as thermal radiation, heating the surrounding material. Progressing in time, an increasing part of the energy is consumed by heating and melting and evaporation of electrode and cladding material, known as the thermal phase. Finally, hot gases at a high pressure, carrying gleaming particles, are emitted to the surrounding. To protect individuals in the vicinity as well as the substation and adjacent functional units, the design of the system is challenged to withstand those effects of a fault instance.

Modern simulation tools basically allow to predict the effects caused by an internal arc. The finite element (FE) method is a suitable tool to address that issue, for it provides the required spatial and temporal resolution. In FE analysis, the fluid volumes of a switchgear or controlgear system are first divided into a mesh of finite volumes, for which then the coupled Navier-Stokes equations are solved by means of a computational fluid dynamics (CFD) code.

For the GHA, three-dimensional FE-models were set up with a simplified arc model implied. The model geometry for iCC is shown in Fig. 2.

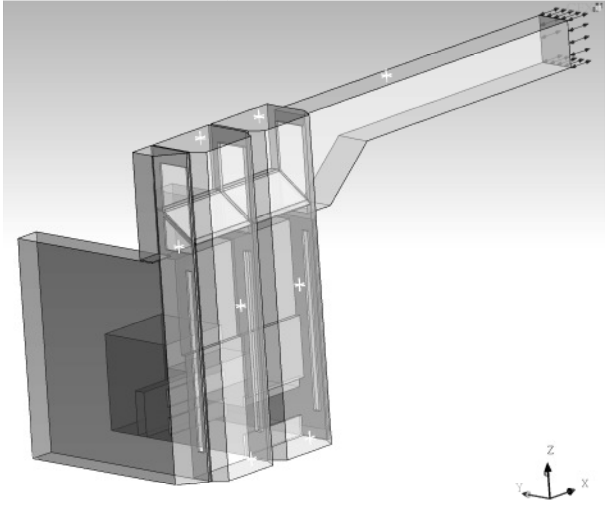

Fig. 2: CFD model of a system of two GHA single busbar functional units with a pressure relief channel

The model resembled a system of two GHA single busbar functional units with a pressure relief channel. The geometry consisted of the volumes of the cable compartment and the pressure relief channel. The opening of the channel is at the far end of the 2000 mm length exhaust duct, where hot gases are released to the ambience outside a container. Cross symbols indicate the pressure measurement points.

The maximum peak value and the rise time of fluid pressure as well as it's spatial distribution are of major interest for the design with respect to the stress on the switchgear and the channel. This peak value usually is reached within the first 20 to 30 ms after ignition, or after opening of a pressure relief device, in systems consisting of two functional units. When focussing to the first milliseconds, effects in the subsequent thermal phase of the internal arc fault can be neglected in first approximation.

A modified ideal gas model for air was used in the calculation with a temperature dependent specific heat, that covered the dissociation and ionisation energy losses of the gas.

An electric arc, which is initiated between the cables with feeding from the bus bar, will move to the furthest distant end of conductors from the power supply. There, it expands into the air volume of the cable compartment, driven by magnetic forces. The magnetic, electric and thermal forces keep the arc moving. In simulation, the lighting arc was modelled as a volume heat source, that was applied to a small volume fraction of the cable compartment. This volume fraction resembled an estimate of the volume, into which the electric arc most likely will expand to. Since the focus was on the first milliseconds after ignition and since radiation losses as well as a temperature dependent specific heat capacity was considered, there was no need to define a power transfer coefficient, as usually introduced in such calculations.

The electric power supplied to the arc was calculated from the short circuit current as a function of time and a constant voltage. Fig.3 shows the calculated electric power together with the measured arcing power for iCC. The short-circuit current was 34.8 kA (87 % of 40 kA), in accordance with IEC specification.

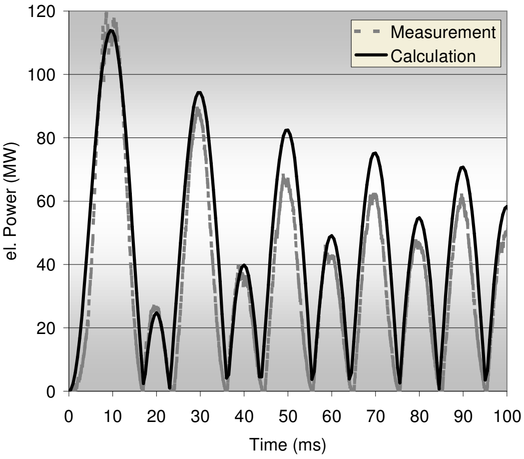

Fig. 3: Model electric arc power compared to measurement

Fig. 4 shows the measured pressure together with the calculated pressure rise at the front door of the cable compartment. Soon after ignition of the electric arc, there is a steep increase of pressure in the cable compartment. The first peak in this increase is due to the direct incident pressure wave at the measurement point. While overall pressure still increases by heating of the gas, oscillations show up in the pressure curve. These oscillations come from reflections of the pressure wave.

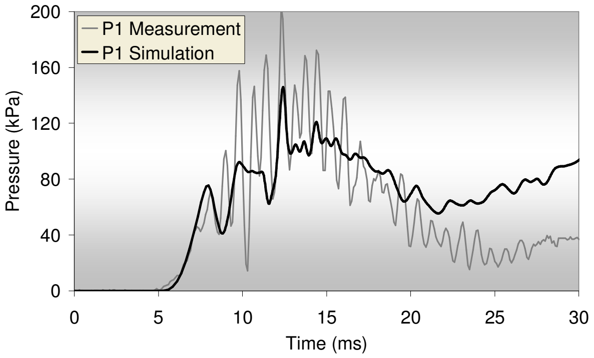

Fig. 4: Pressure in the cable compartment (iCC)

The calculation reproduced the measurement results well over the first milliseconds. Since some power losses were neglected, the pressure rise after the first 20 ms is overestimated. Reflections of the pressure wave are not fully resolved in the simulation, due to geometric simplifications of the cable compartment geometry and the interior components.

With increasing distance from the source, the peaks in the pressure course become less pronounced, because of damping and superposition of pressure waves. Fig. 5 shows the pressure at the top of the channel of the tested unit.

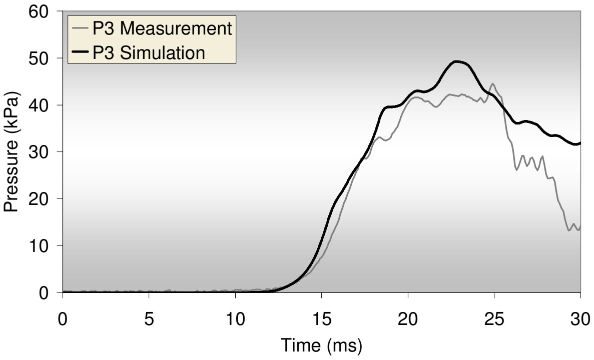

Fig. 5: Pressure at the top of the channel

The design of the channel modules provided openings interconnecting the modules and also to a channel volume at the lateral side walls of the system. This allowed for attenuated expansion of the pressure wave throughout the channel system while reducing pressure load at the origin unit. Fig. 6 presents the pressure at the tapering of the exhaust duct.

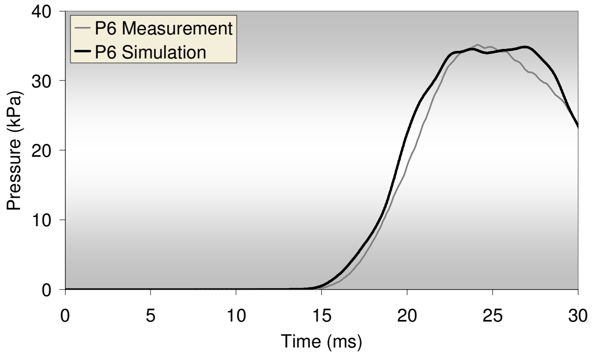

Fig. 6: Pressure at the tapering of the exhaust duct

Simulations were carried out in the development stage and had a major impact on the design. Resulting pressure levels, for example, determined the design of the front door of the cable compartment and of the joints of the channel system, as well as of the interconnection openings. Analysis of the temperature distribution and fluid velocity helped to decide on need for thermal shielding.

Eventually, combining experience with modern simulation tools allowed for successful testing according to IEC 62271-200, wile reducing the need for cost intensive test cycles.

SUMMARY

Experiences with IEC 62271-200 in case of internal arc testing of medium voltage switchgear were presented. The comparison of individual requirements of national and international users, utilities and industries, and the definitions of the IEC-standard for internal arc test were discussed. The need for modern simulation methods in the development of a new product was stressed, in order to comply with the stringent requirements of the new standard. Simulation and type test results for one of the internal arc tests according to the standard were presented and compared.

REFERENCES

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