INTERNAL ARC BASED INNOVATION FOR MEDIUM VOLTAGE SWITCHGEAR

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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. However, because of the strong competition, the development time and costs available for designers are being reduced from year to year. This makes the task extremely difficult forcing the developer to pursue new directions in product development.

This paper describes a new development path, so-called "internal arc based" as well as the successful qualification of the switchgear "GMA Efficient" (gas insulated switchgear) in accordance with the applicable IEC standard and in compliance with the above mentioned requirements. It also describes a few important design rules and innovations, which were necessary to achieve this result. Furthermore it demonstrates how expertise and numerical analysis throughout the development phase are critical to the success of a cost, size and performance optimized switchgear design.

INTRODUCTION

Internal Arc (IA) 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 (up to 7 bar in gas tanks / 1 bar in air insulated compartments and a few hundreds of mbar in the buildings) and overheating (up to 30000K in the arc core and up to 1000K in the immediate environment of the failed compartment) into the environment [1].

The next effect of IA is a more or less significant expulsion of hot gases, flames, fumes and glowing particles which can also endanger humans and equipment.

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 IA 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 IA considerably.

MV metal enclosed switchgears with an IA-Classification (IAC) are qualified according to the standards IEC 62271-200 [2] or IEEE C37.20.7 [3] and have the highest degree of personnel safety. For this reason, MV switchgears without IAC can rarely be found today [4], [5].

INTERNAL ARC BASED DESIGN

The market requirements in terms of IA fault protection differ in the degree of accessibility (AFL: front and lateral accessibility of operating personnel & 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 insulted switchgear type was divided into four variants 450mm / 600mm / 800mm and 1000mm according to the current ratings 800A / 1250A / 2500A and 2500A-Bus 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. In order to solve this problem in the here considered case, an internal arc based design was chosen for the complete product series. The basic (core) element for this design is a 450mm wide switchgear with an IAC rating of 31,5kA/ 1s/ AFL. All necessary design features of the different parts and components of this core unit have then been defined during the first development IAC-tests. Key concepts such as pressure-relief, door-lock and ventilation were determined as part of these first IAC tests. A first new patent (labyrinth seal and locking system) for the door of the cable compartment was one of the first outcomes.

In the next step, the design for the other widths was defined by extending and adapting this core element to the higher current ratings. No more than one IAC test shift was needed to incorporate a new patented arc catching system as well as additional stiffeners needed to cope with the increased widths. In order to fulfil the requirement AFLR-IAC with pressure release into the installation room, a modular upgradable chimney system was fitted for all widths without modifying anything else in the AFL core system. A new concept for releasing hot gas and glowing particles into the room, the so-called "introverted release" system was implemented into the chimney system to successfully pass the IAC-type tests.
In the last step of IA Qualification, only two measurements were needed to achieve the IAC-AFLR with pressure release into the atmosphere: the first one is a modular and user-friendly duct system which can be easy mounted at the end unit of the switchgear installation; the second one is a new anti arc ventilation system (a highly reliable non-return flap combined with ventilation-device), which is necessary to prevent any release of hot gases and glowing particles into the installation room during an IA fault. Such a requirement is usually needed in Oil & Gas industries. All remaining type tests such as temperature rise, dielectric and mechanical tests were then successfully finalized after the IA Qualification. The complete qualification of the whole product-series according to the IEC 62271-200 standards was achieved with just 3 years (2010-2012).

CHALLENGES AND TROUBLES IN THE QUALIFICATION CAMPAIGN

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 IA 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 IA fault?
- How to ease user maintenance and operation
- More generally, how to reduce production costs ?

MAIN DESIGN RULES

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

The following rules were established and successfully pursued to achieve the above requirements:

- Designing pressure resistant, sealed, rigid doors and end walls, that require minimum additional tools
- No additional deflectors or parts which may increase the dimension of the switchgear above the originally desired values
- Modular and scalable design
- Solid-insulated bus bar
- Compact and modular design of the pressure release chimney and duct

ABOUT INNOVATION AND NEW CONCEPTS

This section presents the most important innovations which are key for an improved and more efficient design in the area of IA withstand

Labyrinth and sealing system on switchgear doors

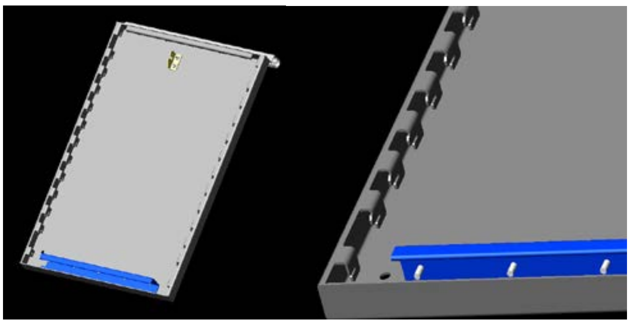

Figure 1: Improved CC door

Due to the market trend in direction to higher IA performance existing door designs must be improved to avoid an impact to the user in case of an internal failure, e.g. in the cable compartment. A combination of labyrinth and

sealing system in order to reduce leakages and increase the mechanical strength is one step ahead. With rising pressure in the beginning of an IA event the connection of bended hooks on door and base frame will increase its strength of linkage due to the deformation on the cable door itself.
ANSYS structural mechanics simulation in combination with pressure data out of Theta-Network-Tool where used to show up the weak points before testing and lead to optimization during the design of new hook-connection of base frame and cable door. In addition the calculation show the need of additional screws on bottom to avoid hooks sliding out of connection in vertical direction.

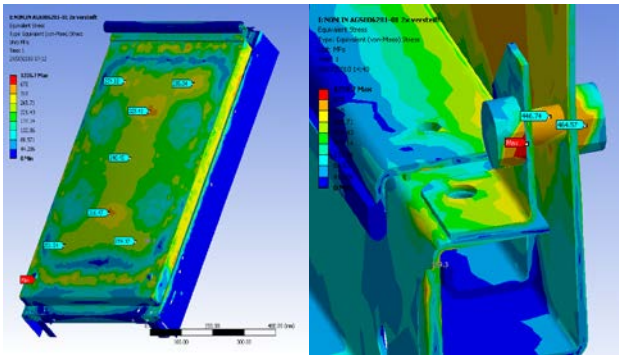

Figure 2: CC door, load calculation on structure and screw

In addition to the strength optimization the labyrinth is designed with nearly no clearance and generate in the end a nearly closed box to avoid the exhaust of glowing particles and hot gases as much as possible.

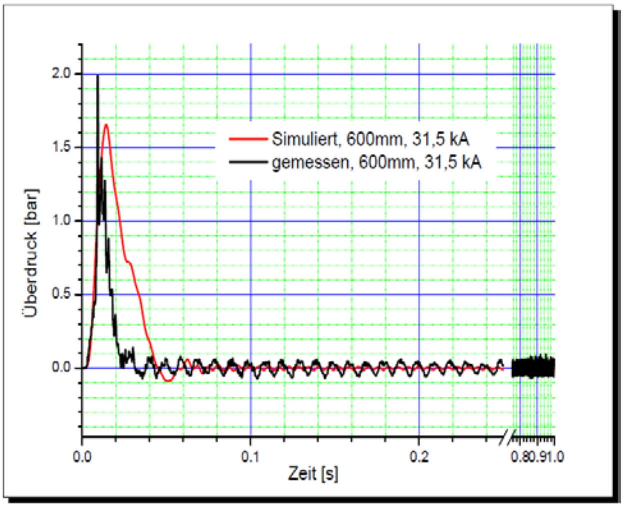

Figure 3:Pressure simulation compared to measurements

Arc Catching System (ACS)

In order to protect the enclosure against burning through and to reduce the dissipated arc energy which mainly defines the resultant pressure rise after an IA fault, a new arc catching system was necessary to control and slow down the migration of the arc roots. The following picture shows one variant of the ACS implemented in the new gas insulated switchgear Type.
The operating principle of the new catcher is based on the substantial increase in the electric field at sharp arrangements. The root points of high current arcs have temperatures in the range of some thousand Kelvin and therefore are able to melt through the conductive material already within a few milliseconds. The burning through time t depends on the arc current value I and the thickness d of the material at the arc roots and can be described with the following equation: $t \sim (d^{\alpha} / I^{\beta})$, eq. (1)
α and β can be determined only empirically. The arc always opposing its cause like any other physical quantity will rounds down the first infested sharp arrangement (tooth) within few milliseconds. In order to prolong the catching effect a high number of sharp arrangements (saw tooth) were installed close to each other. In this way, after melting the first tooth the arc will jump immediately to the adjacent one. The Result is a noticeable prolongation of the catching effect which means a significantly reduction of the transferred arc energy and a prolonged protection of the enclosure against melting through.

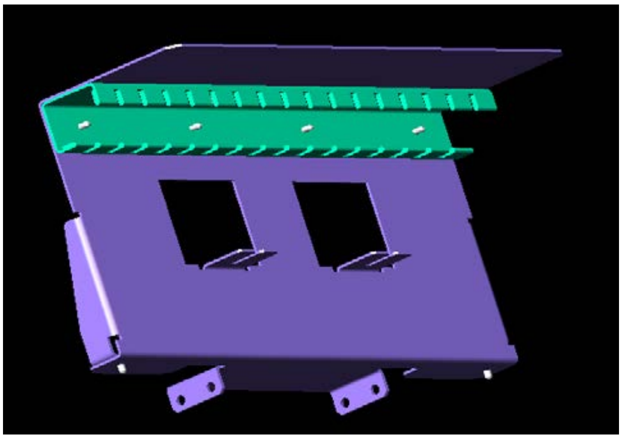

Figure 4: Arc Catching device

Anti Arc Ventilation System (AAVS)

A challenge for a ventilation system is always to find a compromise between preventing the ejection of hot gases and glowing particles into the switchgear room in case of an IA event without downgrading its thermal behaviour during normal service conditions at rated currents. The new system is based on flaps with low-friction bearing points in the metal structure closing very fast during first milliseconds of pressure rise. To avoid the reopening by pressure waves the flap is kept in closed position by implemented springs in the cassette design. In addition the flap enters a nearly closed cassette design on the supporting structure which avoids generating a counter pressure behind the flap by pressure bypass. At normal service condition the flap system will not influence the thermal behaviour as the airflow is not blocked by small grids or metal structures.
The figure 4 shows one AAVS installed as fresh air supply

on the bottom and two AAVS on the upper side of an switchgear to optimize ventilation and heat transport.

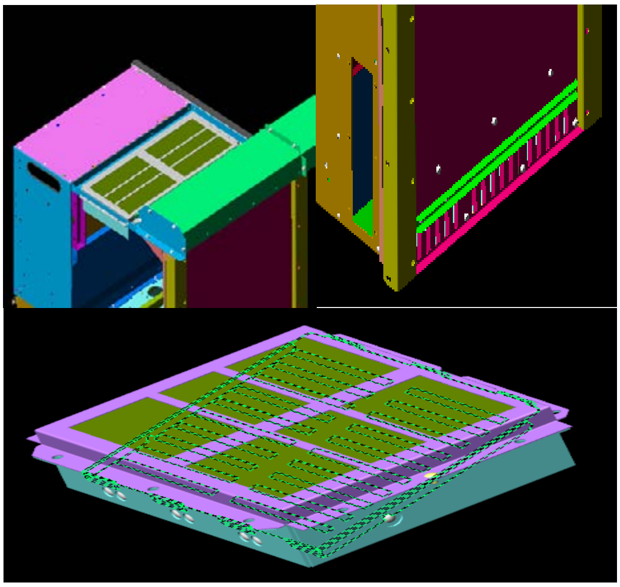

Figure 5: Ventilation devices with flap system

<u>Pressure release concept</u>

Because of the compactness and the relatively low height of new switchgear type a new concept has been pursued for the release of hot gases and glowing particles during an IA fault. The so-called introverted concept is based on the idea to direct the flow of hot gases into the interior of the switchgear enclosure before the end release into the installation room. This is achieved by carefully dimensioning and placing reflectors along the release ways of the ejected materials during an IA fault.
The following sketch illustrates the functional principal:

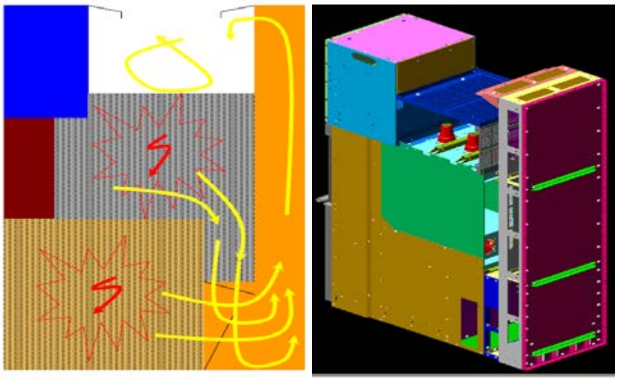

Figure 6: Example of introverted release

RATINGS OF THE NEW SWITCHGEAR

Rated voltage:	24kV
Rated current:	2500A
Rated frequency:	50 / 60Hz
Rated short circuit current:	31,5kA / 3s
IA Rating:	31,5kA/1s, AFL / AFLR

CONCLUSION

The internal arc based development and design improvements described above were made possible through the combination of expertise and the extensive use of simulation tools. It has been also shown that it can be a cost-effective design process. The benefit for the customer is both a higher performance at reduced foot prints as well as a maximum human safety.

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