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New Arc Resistant, Compact Metal Clad Switchgear: Meeting ANSI / UL Design Challenges

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Executive Summary

There is an unfilled market need for a medium voltage (5 kV – 15 kV), arc resistant, compact metal clad switchgear for a variety of applications such as data center, marine and critical health care facilities, etc. However, meeting the ANSI/IEEE/UL design challenges to come up with such compact, front accessible switchgear has been very difficult so far. This white paper discusses the ANSI/IEEE Standards and explores the design challenges to find a solution to the multi-dimensional optimization problem. Analysis and simulation methods to find an optimal design solution are explained. Some of the testing methods used by UL to test arc resistant switchgear are highlighted. An example of IEM Vesta metal clad switchgear is used to illustrate the test results.

Medium Voltage Metal Clad, Arc Resistant Switchgear – Need for a Compact Assembly

Medium voltage switchgear houses electrical components, for example, circuit breakers, potential transformers, current transformers, control power transformers, etc. The medium voltage switchgear typically occupies a large space. As such, maintenance and space considerations are driving factors in the design of new medium voltage switchgear. Furthermore, a certain amount of space is essential between adjacent equipment and structures such as walls and the switchgear as per the national electric code (NEC) and other local codes. An entire room is typically allocated for the medium voltage switchgear. Space is a critical factor in industrial applications, data center facilities and marine equipment. Allocation of an entire room for the medium voltage switchgear would constitute undesirable and inefficient use of a significant amount of valuable floor space.

Switchgear, particularly medium voltage switchgear, suffers from damage due to arcing. An explosion due to arcing, occurring within switchgear causes significant amount of economic loss due to interruptions of energy distribution and results in destruction of the switchgear and the components or equipment accommodated in the switchgear assembly. Furthermore, maintenance personnel inspecting and servicing the switchgear cabinets have to wear bulky and expensive protective gear. Typical arc resistant switchgear cabinets tend to be very large, for example, cabinets are 36 inches wide and 90 inches deep and often have heavy sheet metal enclosures. Such configurations require enormous space. Some switchgear cabinets employ an external arcing chamber which limits the configuration of components, equipment, etc. within the switchgear.

There is a need for constructing a switchgear assembly that makes efficient use of the available floor space and minimizes the time required for inspection, repair and maintenance of equipment accommodated in the switchgear. However, a design of compact, arc resistant metal clad switchgear at 15 kV that meets North American standards is quite challenging.

Medium Voltage Switchgear Standards World-wide and ANSI Design Challenges

Medium voltage switchgear cabinets available in markets such as Europe and Asia are built according to the International Electro-technical Commission (IEC) standards. However, these switchgear cabinets have cable connection in the rear making it very difficult to install and service such equipment. In addition, this switchgear utilizes “bar” type current transformers that are mounted in the rear making it impossible to replace in the field if they fail. And per IEC standards, barriers between compartments are not a requirement so cooling the circuit breaker is much easier.

Medium voltage, metal clad switchgear for the North American market need to meet stringent requirements of Institute of Electrical and Electronics Engineers (IEEE) and American National Standards Institute (ANSI). As per these standards (UL testing is done to meet this standard), the circuit breaker is tested inside the switchgear with very limited cooling and therefore limiting temperature rise becomes a major challenge. IEC designed equipment would have to be derated significantly if no changes are made to adequately cool the breaker. In addition, IEEE / ANSI designed equipment requires the bus bars to be insulated, making it more difficult to cool the critical current-carrying bus bars in certain compartments of the switchgear housing the circuit breaker. Alternatively, expensive heat sinks have to be employed to limit temperature rise. The addition of heat sinks is a difficult task in the compact space and poses significant challenges to pass the required lightning impulse test due to space limitations and the shape of the heat sink. The shape of the heat sink can pose a threat to the space limit, as sharp edges of the heat sinks will require large spacings and creepage distances. Compact switchgear also limits the space between phase-to-phase and phase-to-ground which poses significant challenges to pass the required lightning impulse test at 95 kV.

Arc Resistant, Metal Clad Switchgear – ANSI / IEEE Standards

Arc resistant switchgear provides a means for improving the safety of the operator by providing an efficient method of redirecting the energy caused by an arcing fault away from the operator. Some of the characteristics of an arcing event are the following:

- Temperatures can reach 35,000°F which causes severe burns.
- Copper expands by a factor of 67,000 when it turns from solid to vapor instantly.
This creates high pressure, sound and shrapnel.
- The pressure can easily exceed hundreds of pounds per square inch which can easily destroy doors and walls of a switchgear enclosure if they are not well designed.
- Sounds from the resulting high pressure can exceed 160 dB which causes ruptured ear drums.
High pressure also causes collapsed lungs.
- Material and molten metal is expelled away from the arc at speeds exceeding 700 mph, fast enough for the shrapnel to completely penetrate the human body.

In order to define and standardize metal clad switchgear construction and testing to deal with the enormous energy of an arc fault, the following standards were created by IEEE / ANSI / NEMA:

ANSI / IEEE C37.20.2-1999: Standard for Metal Clad Switchgear.

ANSI/IEEE C37.55-2002: Metal-Clad Switchgear Assemblies – Conformance Test Procedures

ANSI/IEEE Standard C37.54-2002: Standard for High Voltage AC Circuit Breakers –Conformance Test Procedures.

ANSI/IEEE C37.09-1999: Standard Test Procedure for High Voltage AC Circuit Breakers

ANSI / IEEE Standard C37.20.7-2007: IEEE Guide for testing of Metal Clad Switchgear Rated up to 38 kV for Internal Arcing Faults (this standard replaces EEMAC G14-1987 and CSA C22.2 No. 261 adopts much of the language from IEEE C37.20.7-2007).

CSA/CAN C22.2 No 31 -04 -2009: CSA Standard for Switchgear Assemblies.

In addition, we have NFPA guide and IEC standard (for reference only) below.

NFPA 70E-2009: Handbook for Electrical Safety in the Work Place.

IEC 62271-200: Standards for High Voltage Switchgear and Controlgear.

Arc Rating for Metal Clad Switchgear

There are two basic types of arc ratings.

Type 1: Switchgear with arc resistant designs or features at the freely accessible front of the equipment only.

Type 2: Switchgear with arc resistant designs or features at the freely accessible exterior (front, back and sides) of the equipment only.

The Vacuum Circuit Breakers: Recent Advances in Materials and Technology

The performance and reliability of a vacuum circuit breaker has been enhanced by recent advances in vacuum interrupter technology. New vacuum interrupters incorporate better contact materials such as chrome-copper, and use axial magnetic field (AMF) or radial magnetic (RMF) field contact systems. In addition, these breakers are magnetically actuated (with a solenoid) incorporating built-in capacitors that store the operating energy, and electronic trip units. These breakers have fewer moving parts compared to mechanically (spring) operated breakers and have proven to be much more reliable in enhanced life-cycle (torture) tests and in installations world-wide. ABB VM1 and Eaton VCP-TL are examples of such magnetically actuated breakers. These breakers are designed to perform 100,000 operations without failure due to much lower number of moving parts. These breakers almost look like low voltage breakers and if the ANSI/UL design challenges are met, a 15 kV metal clad switchgear's foot print would be about 25% lower than that of low voltage switchgear handling equivalent power. The reliability of such medium voltage switchgear would also be substantially higher. Such a product would offer substantial space saving for mission critical data center, marine and other applications.

Front Accessible, Arc Resistant Metal Clad Switchgear: Target Parameters

The following parameters were considered when designing new metal clad switchgear:

- Front accessible
- Target Size: 24"W x 60"D x 96"H
- Arc resistant, class 2A
- IR viewing ports and viewing windows
- Front accessible 600V CTs and front connected cables
- Draw-out Breaker (magnetically operated VM1), PT and CPT
- Insulated Bus
- UL and cUL listed per ANSI / IEEE standards (metal clad and arc resistance)

Design Challenges

The compact foot-print posed significant design challenges to be able to accommodate conflicting requirements. For example, lightning impulse tests at 95 kV required larger phase-to-phase and phase-to-ground spacings that compact foot-prints did not allow. Also, providing adequate cooling at rated currents required larger space and better air circulation that was not possible in a compact design. Adding to the design challenge was the fact that the switchgear had to meet arc testing requirements which dictated that the switchgear was efficient in the way the arc was exhausted.

Design Solution through Extensive Simulation

Based on experience, it became clear to us that extensive simulation would be the best approach to come up with a suitable solution to such a multi-dimensional optimization problem. IEM did extensive mathematical analysis of the following: (1) thermal characteristics of the switchgear to study the temperature rise and hot spots at rated currents, (2) electromagnetic force analysis of the switchgear during faulted conditions such as short circuits, (3) dielectric analysis during lightning impulse tests and (4) analysis of propagation of arc and gases and resulting pressure build up in various switchgear compartments during an arcing fault. The benefit of this extensive simulation enabled us to define our initial solution that was then used to build prototype units for testing. Without the benefit of extensive analysis, a solution would have required extensive testing by trial and error, requiring a large number of samples and very expensive testing costs. Also, the trial and error testing approach would have taken an

enormous amount of time without a guaranteed arrival at an optimal solution. We worked closely with ABB design engineers in Dalmine, Italy throughout this project. Without ABB's help and guidance, this project would not have been completed in such a short time. The arc testing is discussed in more detail in the following section to highlight the benefits of a good design and to highlight some of the test methods used to ensure the safety of the operating personnel working on "arc resistant" switchgear.

Arc Testing – Cotton indicators

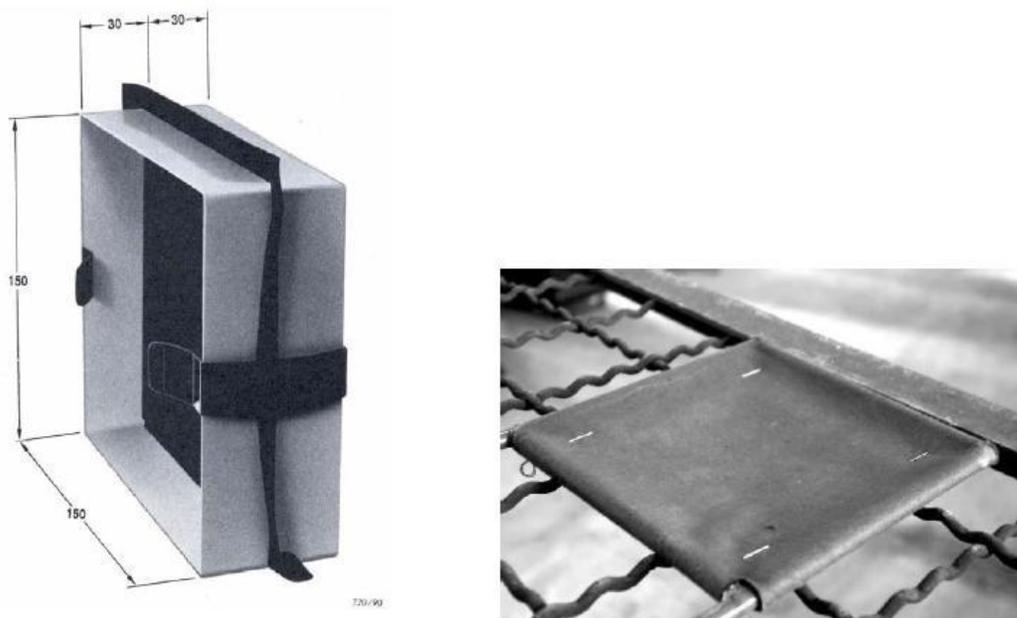


Figure 1: (a) Vertical indicator

(b) Horizontal indicator

The cotton indicator is 150mm x 150 mm (6" x 6") and is supported as shown in Figure 1.

Figure 1(a) shows the vertical indicator and Figure 1 (b) shows the horizontal indicator that are used to test the ability of switchgear to efficiently exhaust the gases and arc without any leakage in the area where operating personnel would be present. The cotton indicator material shall be untreated for fire retardance and be of 100% black cotton with a density of 150 g/m². The weave is defined as Cretonne which is a strong fabric with cotton warp and woolen weft.

Example: IEM Vesta Switchgear Testing for Internal Arcing Faults

IEM Vesta is designed as Type 2 arc resistant switchgear meaning that it is arc resistant for features at the front side and the back. Consequently, during testing, cotton indicators are placed at the front, sides,

and back as well as below the plenum, to make sure that the operator working on any of the sides of Vesta switchgear is safe.

Arc Resistant Design Considerations

In order to be thoroughly arc resistant, metal clad switchgear must be safe for the operator when there is an arc in any of its compartments.

Figure 2 shows a simple side view of Vesta switchgear that was used for testing. Arc has to be initiated in each of the compartments, one at a time and the equipment must successfully exhaust the arc and gases without burning any of the indicators.

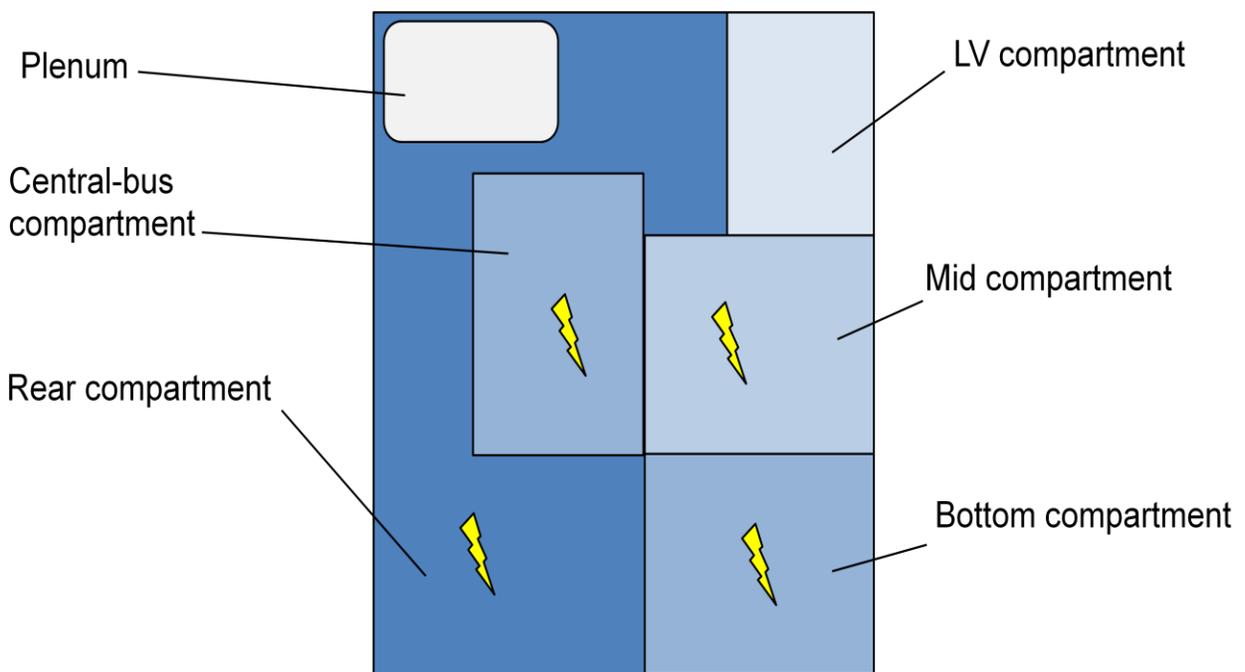


Figure 2: Switchgear testing for internal arcing faults

Vesta Arc Testing Set Up

Figure 3 shows Vesta arc testing in the breaker compartment. A plenum (2 meter long) is used for testing as per IEEE guidelines. Since this design vents the gases through a plenum and building ducting system, no room simulation is necessary.



Figure 3: Vesta Switchgear set up for Arc Test at KEMA, Chalfont, PA

If the arc resistant design vents the gases inside the building through an opening at the top then such design would involve room simulation during testing so that the gases and shrapnel bouncing from the ceiling would not cause any damage to any of the horizontal indicators. The vertical indicators are placed 4 inches from the test unit and horizontal indicators are placed 4 inches below the plenum and at 79 inches level as shown.

Arc Test Performance and Pass/Fail Conditions

What constitutes an arc test failure? Per IEEE standard, a failure is indicated by violation of any conditions listed below.

- There should be no permanent deformation of the structure and secured covers and doors do not open. Slight bowing or other distortion is permitted as long as such deformation does not extend to the indicator mounting.
- No indicators burn. However, pin holes and discoloration of indicators is permitted
- Ejection of small parts (up to 60 g) through the plenum is permitted. No parts are allowed to eject through seams or doors of the structure. A high speed video is used to further analyze the results of an arc test if needed.
- All grounding connections remain effective after the test.

Example: Failure of an Arc Test



Figure 4: Failure of an arc test – highlighted indicator burned completely

Figure 4 shows failure of an arc test on Vesta. One indicator is burned completely causing the failure. We made changes to the design and retested again to pass this test.

A Successful Arc Test

Figure 5 shows a successful arc test done at KEMA Power Test lab in Chalfont, PA. The arc and gases exhaust through the plenum as designed. Also, the structure did not bow appreciably and no cotton indicator was damaged in any way. It was done on a day when there was snow falling and one can see particles of snow with the exhaust gases in the picture. The IR windows used on Vesta did not rupture during the arc tests. Consequently, IR scanning of Vesta can be done with the equipment energized wearing no protective gear.



Figure 5: A Successful Arc Test of Vesta

IEM Vesta – Compact, Arc Resistant Metal Clad Switchgear in North America

IEM Vesta switchgear is now UL and cUL listed and represents one of the smallest foot-prints on the market. This challenging switchgear design was completed through extensive simulation and testing. Front access to CTs was a challenging design problem that was solved through an innovative design of the insulator assembly. Epoxy coated bus is a standard feature on Vesta along with IR windows and viewing windows.

Various configurations are available to accommodate different custom switchgear requirements. In addition to front access assembly, Vesta is also available with front and rear access in 72” deep switchgear.

Conclusion

An arc resistant, compact metal clad switchgear design is presented in this paper. A review of ANSI/IEEE standards is detailed along with testing standards for arc resistant switchgear. A metal clad switchgear solution based on extensive analysis and simulation is presented. IEM Vesta switchgear is used as an example to highlight UL arc testing methods used to certify arc resistant switchgear.

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Authors

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