PRESSURE RISE IN SWITCHGEAR ROOMS IN CASE OF INTERNAL ARC IN AIS MV SWITCHBOARDS: IMPORTANCE OF ROOM DESIGN AND SIMPLIFIED CALCULATION METHOD

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ABSTRACT

In some cases, hot gases generated by internal arc fault are released into the switchgear room, which is subjected to a pressure rise. Pressure development in time and space is studied in this article thanks to a CFD software, for typical AIS switchgear rooms. A focus is made on the room space-averaged pressure, which appears to be critical for wall sizing. To derive this result simply, a simplified engineering method is proposed, which can be implemented in an Excel sheet. Dynamic considerations are proposed, as well as order of magnitude of pressure peaks occurring locally in the room.

INTRODUCTION

When an arc occurs inside a medium voltage Air Insulated Switchgear (AIS), a considerable amount of energy is transferred from the grid to gases surrounding the arc, both air and vaporized material. This induces a pressure rise inside the switchboard, and a flow of hot gases from the arc location to the outside.

Gases are usually driven in a duct, either a cable duct below the switchboard, or a dedicated gas duct above it, and then released outside the switchgear room, which is not subjected to pressure rise – or to a small extent.

In some installations however, gases are released into the switchgear room [1]. This induces a pressure rise in the room, thus a mechanical stress of the building itself. The evaluation of this stress is not simple, as no test can be carried out in real switchgear rooms.

Simulation is a way to evaluate the pressure applied on building walls. A generic CFD software (Computational Fluid Dynamics), including add-ons for arc modelling [2] has been used to derive pressures in typical AIS switchgear rooms. Arc power, room volume and size of room pressure relief opening, are input parameters. The room average pressure is observed, and a simplified engineering method is proposed to calculate it.

Then, local results are studied at two different locations. Dynamic considerations are proposed in relation to these results.

TYPICAL AIS SWITCHGEAR ROOMS

Two types of switchgear have been modelled: a secondary switchgear equipped with fixed CB (ratings 16kA and 25kA), and a primary switchgear equiped with withdrawable CB (ratings 31.5kA to 50kA). Figure 1 shows a typical arrangement of the 2nd case.

In both cases gases are directed upwards, and pressure is released in the room through switchgear flaps, which are supposed to open instantaneously. The room pressure relief opening is supposed to be simply a hole in the wall.

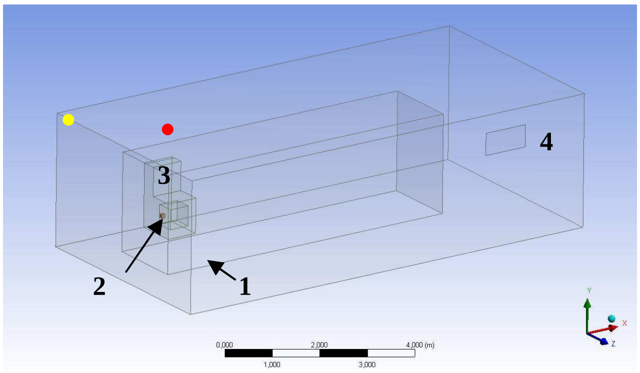

Figure 1 : typical room geometry; case 19

1. The faulty cell is at the left end of the switchgear
2. The arc is located in a withdrawable circuit breaker compartment, including
3. a chimney to switchboard top face. Gases are thus directed upwards.
4. The room pressure relief opening is located at the other end of the room, front wall.

The arc power versus time is defined as in [2], using the Isc rating, and the phase-to-neutral voltage (“arc voltage”), supposed constant. An additional scalar value is defined in this paper, called arc power and written “P”:

P = 3 . Isc . Arc voltage (MW) (1)

The following arc powers are studied:

- 14 MW : corresponds to 16kA – 300V
- 26 MW : corresponds to 25kA – 350V
- 38 MW : corresponds to 31.5kA – 400V
- 54 MW : corresponds to 40kA – 450V
- 75 MW : corresponds to 50kA – 500V

33 simulations were made, they are summarized in table 1. The scalar S is the size (area) of the room pressure relief opening. The CFD software calculates the pressure average value over space, at each time step. The peak value of this curve is reported in table 1.

N°	P (MW)	Air volume in room (m^3)	S (cm^2)	Room peak pressure (Pa)	Peak instant (ms)	kp
1			1000	10000	700	0,36
2		23	2000	4300	250	0,41
3			5000	1900	40	
4			1000	8500	850	0,31
5	14	38	2000	4800	450	0,42
6			5000	1600	60	
7			1000	10000	1000	0,36
8		48	2000	4500	700	0,4
9			5000	1500	100	
10			2000	6500	480	0,28
11		48	5000	2800	98	0,43
12	26		8000	2100	59	
13			2000	6100	900	0,27
14		71	5000	2100	99	0,37
15			8000	1700	80	
16			5000	3900	300	0,36
17		75	8000	2400	100	0,44
18	38		12000	1850	57	
19			5000	3400	400	0,34
20		123	8000	2100	180	0,42
21			12000	1550	98	
22			8000	3500	200	0,38
23		101	12000	2600	80	
24	54		20000	2100	40	
25			8000	3300	300	0,37
26		173	12000	2100	120	0,44
27			20000	1500	56	
28			12000	3450	170	0,41
29		173	20000	2200	60	
30	75		30000	2000	55	
31			12000	2600	300	0,35
32		343	20000	1700	82	
33			30000	1650	80	

Table 1: summary of calculations and results

PRESSURE IN SWITCHGEAR ROOM : SPACE AVERAGED RESULTS.

The room pressure is time dependent, and also space dependent : pressure is not uniform in the room, and varies from one wall end to the other. It is possible to differentiate two behaviours, according to the ratio S/P :

- S/P < 215: when the peak occurs, the pressure is close to be homogeneous, with a distribution within +-20% around the average value. Thus, the average room pressure is representative of the stress applied to walls at this instant of time.
- S/P > 215: the pressure is never homogeneous in space. It is mainly the results of waves propagation, and the local pressure can vary from zero to twice the average pressure on a given wall. The space average pressure is thus not representative of wall stress.

Figure 2 is an example of pressure field in 3D as calculated by the CFD software; figure 3 shows an example of the space-averaged pressure curve, as calculated in CFD, and with the simplified engineering method (SEM) described below.

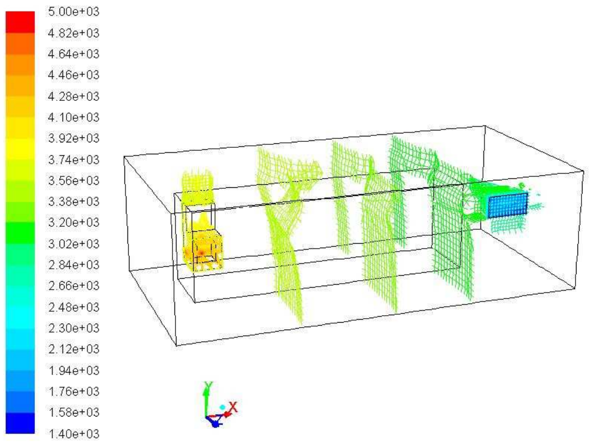

Figure 2: pressure isovalue 260ms after fault initiation, case 19.

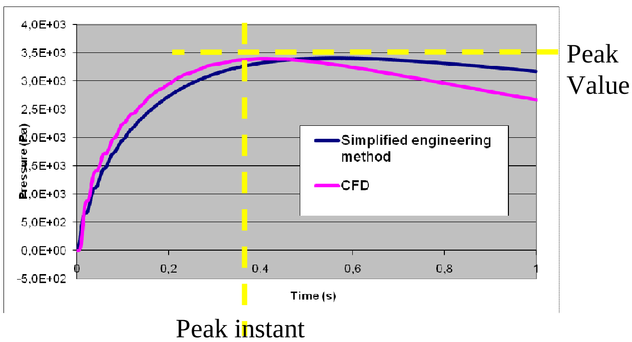

Figure 3: space-averaged pressure versus time, as calculated in CFD, and with the SEM. Case 19.

Results analysis

The most influencing parameter is the size of the room pressure relief opening. The higher this size, the lower is the room pressure. When varying this size, room pressure can be several times lower or higher.

The room volume is of second importance, and influences as follows:

- The higher the room volume, the lower the pressure. For twice the volume, pressure decrease by 10-25%.
- The higher the room volume, the longer the pressure rise and decrease.

Simplified engineering method

An analytic method based on the ideal gas model and the first law of thermodynamics was presented in [3]. This model considers 2 volumes: the one of the compartment in which the arc occurs; and the one of the switchgear room, as summarized figure 4. Scalar values are used instead of a 3D model. Pressure and temperature are supposed to be homogeneous within each volume.

In this model, material evaporation is ignored, and a given part of the arc energy heats the gas. This part is defined by the kp coefficient:

$$dQ = kp \cdot Pel \cdot dt \qquad (2)$$

Where Pel is the instantaneous arc power.

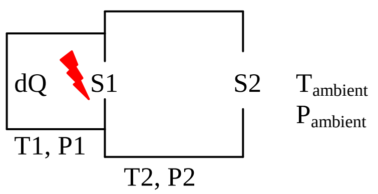

Figure 4: model of the analytic method in [3]

A section S1 (cm²) allows gas flow from volume 1 to volume 2, and S2 from volume 2 to the ambient. A coefficient α is used in the calculation to describe the contracting effect of the gas flow through an opening : each section S1 and S2 is multiplied by the proper α.

This model was applied, with these additional simplifications :

- The switchboard is neglected, and a single volume is modelled: the switchgear room. This is equivalent to consider that the arc is freely burning inside the room.
- All gas quantities are considered constant.
- The discharge coefficient α has a value of 0,8.

Such a simplified model does not to represent all the physics; however, it is easy to implement and does not require computing time and efforts.

The kp coefficient is usually tuned in order to fit the pressure measured in a tested switchgear. The same was done here, with the curves derived from CFD as reference, as in the example of figure 3.

With the proper "kp" coefficient, the shape of the curve is close to the CFD one. The rise is very close, while the decrease is usually slower. The peak instant can be different, but the order of magnitude is correct.

However, when the ration S/P exceed 215, pressure is not uniform within the room: kp was then not calculated in these cases, as the simplified method is not applicable any more.

Estimation of the kp coefficient to use the simplified engineering method in any case

It is noticeable that for a given arc power, the higher the size of the room pressure relief opening, the higher the required kp coefficient.

The following formula is then proposed to extrapolate to any case :

$$Kp = 0{,}29 + 0{,}00095 \cdot S / P \qquad (3)$$

This formula overestimates kp for all calculated cases. Applying the limit of S/P < 215, its validity range is then between 0,29 and 0,49 for kp.

Using this formula and the simplified engineering method described above, the relation between the room space-averaged pressure peak, versus the S/P ratio, is as follows (arc maintained 1s):

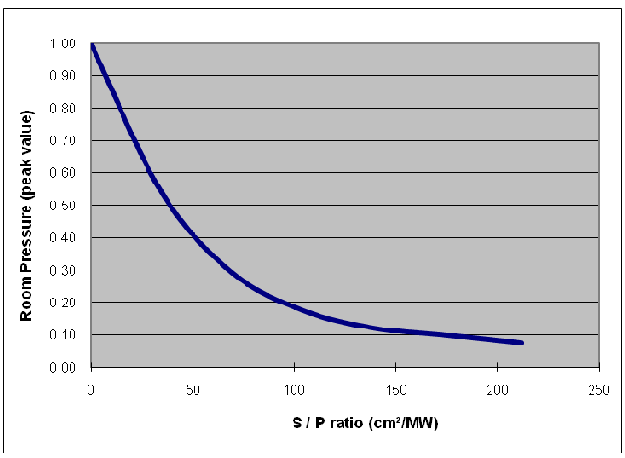

Figure 5 : room space-averaged pressure (peak value) function of S/P ratio

For a proper design of the room, it is preferable to choose a room opening size, which allows to stay below the knee of this curve.

It is pointed out that the pressure relief opening is supposed to be a hole in the wall in this method. Appropriate oversizing shall be considered when using devices such as grids or other porous media.

Dynamic considerations

For the cases where the pressure is never homogeneous in space, it would be difficult to give general information. Such cases should be evaluated in details in CFD, as results would depend on actual room geometry, and pressure relief location(s).

Considering now the cases where the pressure becomes uniform, it comes that the peak is reached between 98ms (case N°11) and 1 s (case N° 7). Pressure decrease lasts from 150ms to more than 1 s.

From this, we deduce that the pressure rise corresponds to a load between 0.25 and 2.5 Hz.

LOCAL PRESSURE PEAKS

Pressure results at two points of interest

At the beginning of the event, pressure peaks appear locally due to wave reflections.

With the modelled switchboards, hot gases generated by the arc are directed upwards. They shoot the ceiling right above the chimney: the pressure was monitored at this location (point noted in red figure 1). Figures 6 & 7 show results at that point.

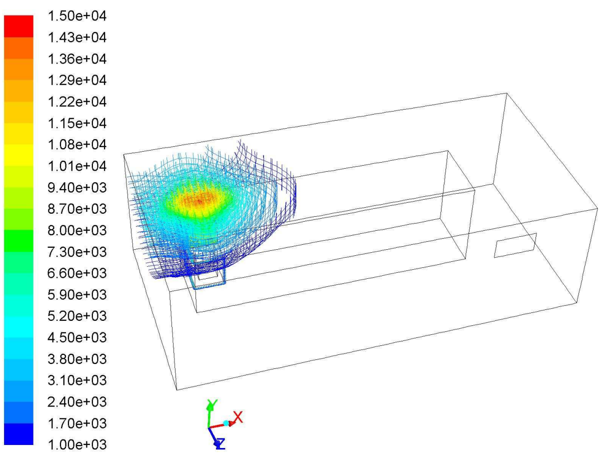

Figure 6 : pressure isovalues 11 ms after the fault initiation, case 19. Example of local peak point 1.

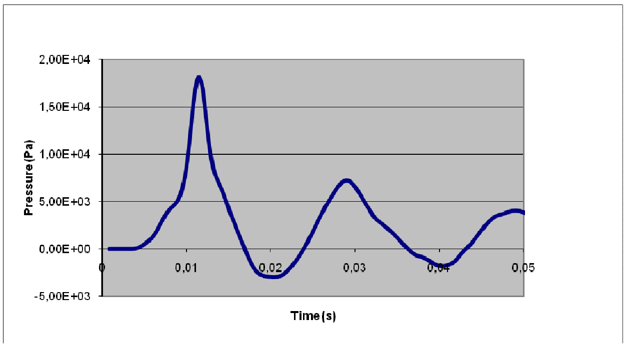

Figure 7 : Pressure point 1 versus time, case 19.

Because of the rectangular shape of the room, the pressure wave reflects against walls, generating peaks in corners. Pressure was monitored in the upper left corner, point noted in yellow figure 1. Figures 8 & 9 show results at that point..

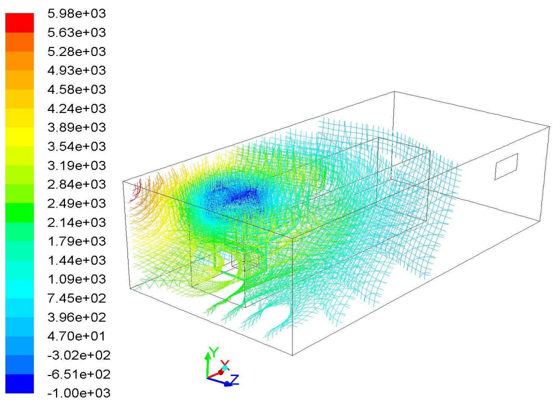

Figure 8 : pressure isovalues 17 ms after the fault initiation, case 19. Example of local peak point 2.

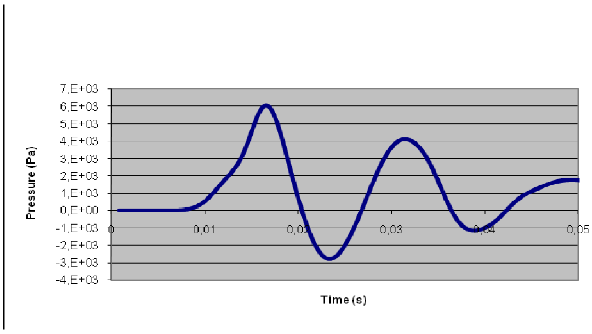

Figure 9 : Pressure point 2 versus time, case 19.

Table 2 : local pressure peaks, CFD simulations results

	Point 1		Point 2	
	(Pa)	ms)	(Pa)	(ms)
16kA	12500	19		
25kA	22500	16	5000	19
31,5kA	18000	11	6000	16
40kA - height 3m	24000	11	6500	16
40kA - height 4m	12000	11	4400	17
50kA	17800	11	6100	17

One observes the following :

At these location points, the order of magnitude of the pressure peak is about 10 times the one of the room average pressure. These peaks are independent from the room volume and from the size of the room pressure relief opening.

They are linked to the arc power, to the location of the switchboard inside the room, and to the room height. The switchboard design also influences, as direct release in the axis of a chimney, where gases accelerate, leads to higher peaks. It has also been demonstrated that such peaks can be reduced using absorbers [1]. An example of absorber is given figure 10.

They appear with the first pressure wave, therefore at the beginning of the event. In the case of point 1, one can state that there is almost no pressure elsewhere in the room at this instant.

In case of point 2, in most of the cases the room pressure is still low when peak occurs; but a pressure not negligible already applies on adjacent walls. Furthermore, several peaks appears later in room corners, smaller than the first one, but of the same order of magnitude. Such peaks may then apply in addition to the room average pressure.

Figure 10: example of a porous type absorber, Schneider Premset range, after internal arc test.

Dynamic considerations

Peaks seem to be an addition of a 50hz load, and a signal of higher frequency, in the order of 100 – 150 Hz.

Peak at point 1 applies on a surface which is in the order of 1 m².

Peak at point 2 applies on a surface in the order of 1 m² on each face : first wall, second wall, ceiling. A lower pressure applies further on these surfaces.

CONCLUSIONS

The uniform pressure applied on building walls, in case of internal arc in an AIS MV switchgear, can be minimized by designing the switchgear room with a pressure relief opening of an appropriate size. The effect of the pressure relief size on the room space-averaged pressure can be estimated quickly using a simplified engineering method, for which a good correlation was found with the CFD. However, above a given limit in the S/P ratio, pressure is not uniform and shall be studied in CFD.

Pressure peaks of high amplitude may also occur in the switchgear room: they are limited to a small area, and also limited in duration. Such peaks can be reduced using absorbers, and with a switchgear design which avoids gas release in the axis of a chimney. Furthermore, the absorbers decrease gases temperature, which contributes also to safety.

REFERENCES

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