New arc flash standards for aluminium rectiformer stations

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Over the last ten years aluminium smelter construction has reached new dimensions, from formerly typically 250,000 tpy potlines to a nameplate rating of more than 500,000 tpy. Over the same time, arc flash standards and operational practices have remained at mid-2000 levels. During recent years, new and ageing rectifier stations have experienced fires. Three incidents were related to HV cable termination failures, and a further two due to ageing transformers without full rated intermediate bushing. In addition, two rectifier containers were damaged by internal arc flashes, one of them caused by a prolonged water leak. These incidents were investigated and have led to the implementation of an elaborate hazard and risk assessment. The authors list below the outcome of these studies, simulation and analyses, and they present new standards for rectifier station design and solutions.

Incidents caused by HV cable termination failures

The fires caused by failures of cable terminations were possible as the transformers lacked a cable bushing oil compartment isolated by a full rated bushing installed in the regulation transformers tanks cover. Where such a risk is identified, the regulation transformers HV bushing must be fitted with fully rated bushings between the cable termination and the transformer windings. This will prevent fires after a HV cable termination failure. HV cable terminations in turn must be of a plug-in type so as to add additional isolation barriers.

Incidents caused by aged transformer

Health, hazard and risk assessment of aged rectiformer transformers needs to be conducted to evaluate the risk of fires if the transformers fail. This may require installation of fire deluge systems in order to reduce the possible damage after a failure (fire). Such systems reduce the risk of conversion station failure and consequent high impact damage, and they may prevent total loss of production.

Rectifier damage caused by arc flash

Around the year 2000 the arc flash hazard within the rectifiers was realized, and pressure relief flaps were fitted to the rectifiers. The industry knowledge, in respect of arc flash energy calculations and simulations, was then limited, but has since broadly advanced. Recent incidents, as described in the introduction, have shown that the assumed arc flash strength and energy were previously not considered or known for the design of pressure relief.

With the latest knowledge of arc strength and arc development, it is now possible to design new rectifier enclosures and to operate them according to arc flash energy simulation standards. Arc flash design, practices and operational procedures already exist in other industries, and smelters will need to adopt them in the future. This will limit rectifier damage caused by arc flash, as already with Medium Voltage Switch Gear.

The installed rectiformer stations need to undergo hazard and risk assessment for arc flash. This will then provide guidance to implement upgrades and operation improvements.

Arc pressure simulation

Several teams inside and outside ABB have extensively studied and simulated pressure changes during an internal arc fault. The simulations of the pressure build up that are presented here are all based on that physical model. The model describes the interaction of the arc with its environment, in particular the exchange of electrical energy with the electrodes and the surrounding gas. About 30 comparisons with experiments have extensively

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HV cable termination failure by fire

HV cable termination plug-in type after failure

Fire damage to aged transformers after internal short circuit and successfully validated this model.

This validation campaign was done for different types of devices (HV-GIS, MV-switchgear, substations). The model is implemented in 0D and 3D. The 0D model is implemented in Dymola and is called DymoDat. The 3D simulation of arc pressure build-up is performed using 3D-Prias, an in-house tool developed for pressure burst simulation, and it is implemented in a CFD solver, Ansys-Fluent. While the 0D simulation yields an averaged transient pressure for the entire volume, the 3D CFD tool yields detailed, spatially resolved information, including pressure waves.

A decisive role is played by flow openings (e.g. burst disks and flaps) that limit the pressure peaks in the enclosed volumes. Naturally, the dynamics of such flow openings cannot be modelled in 0D, so for DymoDat this limit is input data. By contrast, the dynamics of the openings are modelled in 3D CFD, and are thus a result of the 3D simulation. Required input data for this are geometrical and material information.

Calculation of the average arc pressure build-up using DymoDat model

Fig. 5 (left) depicts the schematic representation of the rectifier cabins used in the Dymo Dat model. The arc source is situated inside the main arc room of volume 37.5 m³. The main arc room is connected to the service room of volume 7 m³ via two fans of 0.7 m² total opening area.

Parametric study serves to calculate an optimum effective area of the burst flaps / discs so as the be able to accommodate the maximum pressure peak within a typical rectifier container structure. Burst flaps / discs with an opening pressure threshold of 0.1 bar are installed on the main arc room, where the total opening area varies between 5 up to 9 m².

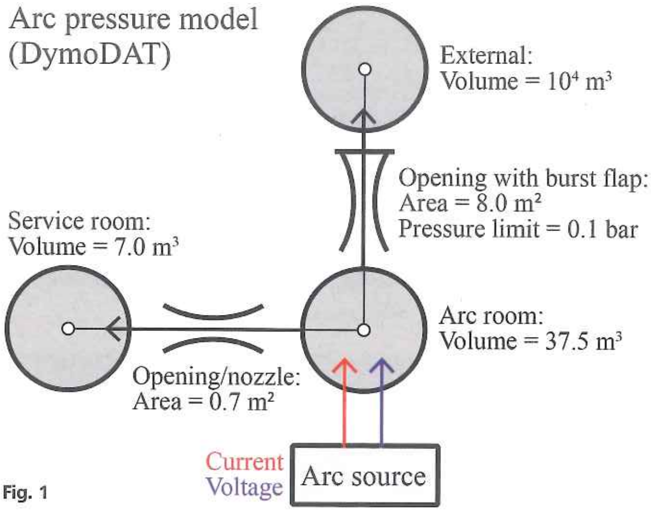


Fig. 1

Figs 1-2: Schematic representation of 0D DymoDat model for the calculation of an arc pressure build-up (left) and for the current and voltage applied to the arc source (right) corresponding to a short-circuit event

Fig. 2 (right) shows the arc current and voltage used as the input for the pressure calculation in 0D DymoDatmodel. The results of the calculations of pressure build-up in a rectifier container are shown in Figs 3-4 for the main arc room (left) and the service room (right). Based on these results, it is recommended that the total effective opening area of the burst discs / flaps should be at least 8 m², in order to keep the peak pressure increase below 0.15 bars in the main arc room.

Figs 3-4: Evolution of the pressure increase inside the main room (left) and the service room (right) during a short-circuit event, for different configuration of effective area of burst flaps / discs.

Full-scale 3D CFD simulation for arc pressure build-up

Full-scale 3D CFD simulations of the arc pressure build-up are performed using an in-house tool 3D-Prias within Ansys Fluent. In the present 3D-Prias / CFD simulation, only the half of the container volume (i.e. the main arc-room and the service room on the left-hand side) is taken into account, which is the same

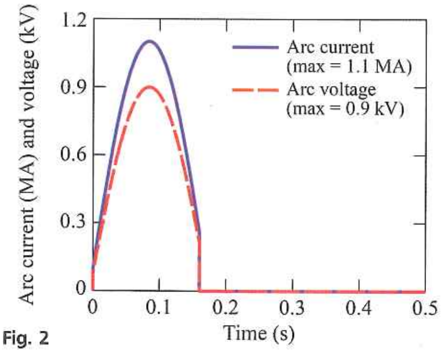


Fig. 2

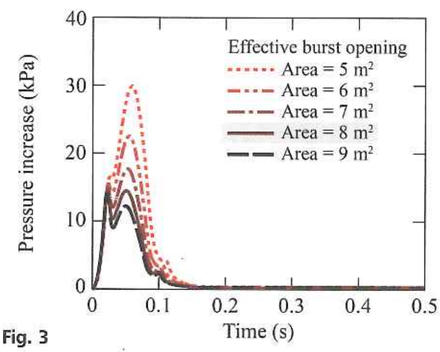


Fig. 3

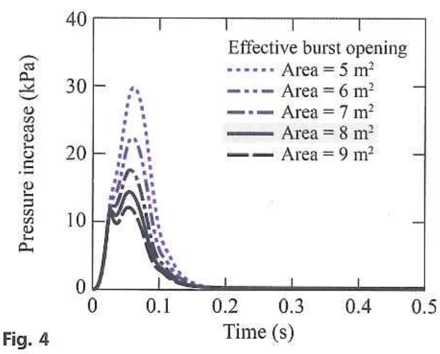
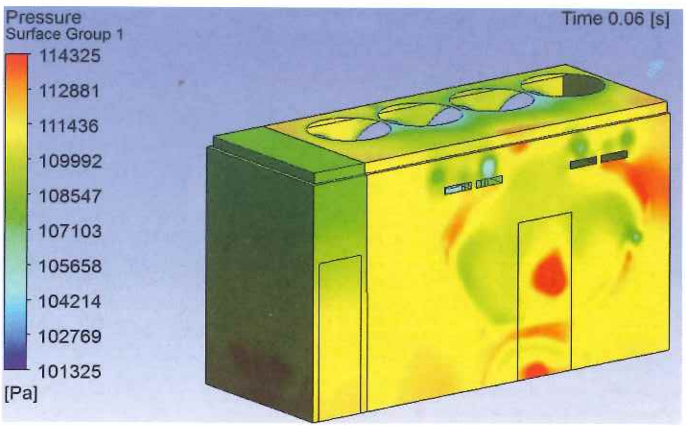
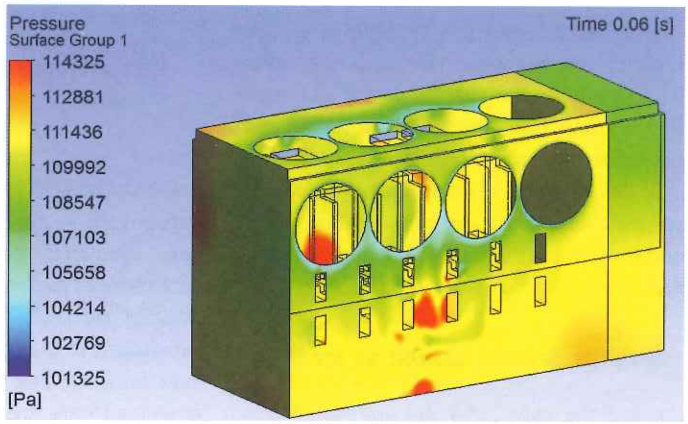
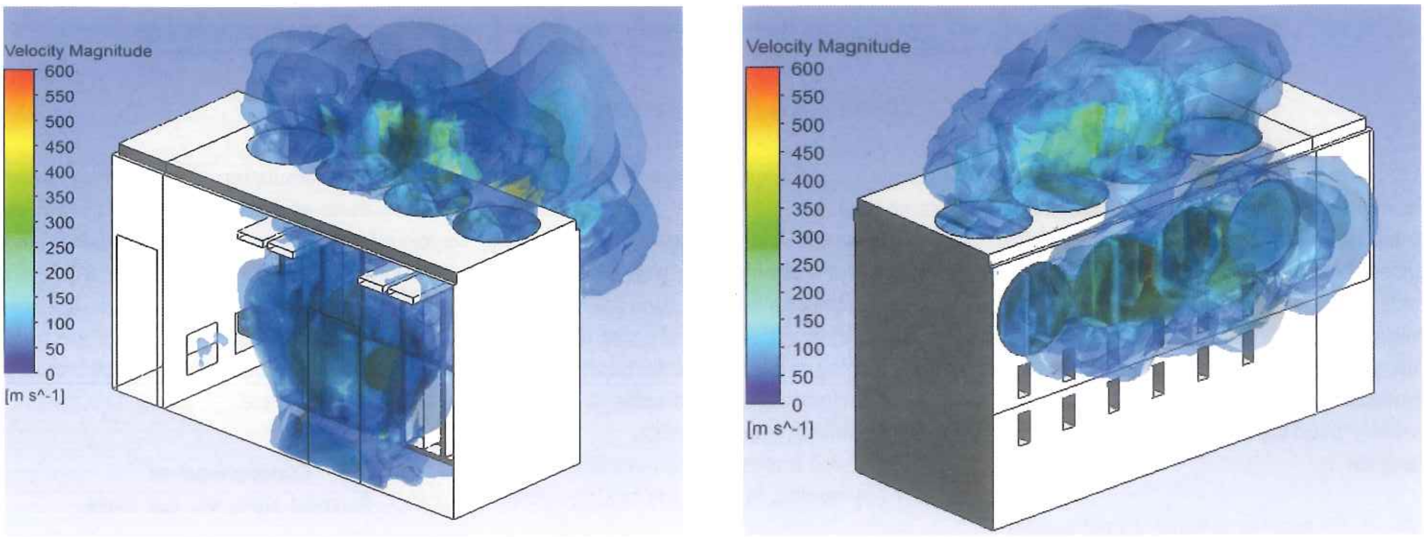


Fig. 4





Figs 5-6: The distribution of pressure acting on container walls at the pressure peak (t = 0.06 s) resulting from 3D-Prias / CFD simulation (unit = Pa)



Figs 7-8: Velocity of the gas due to short-circuit arc event obtained from 3D-Prias / CFD simulation (front and back view, at t = 0.06 s, unit = m/s)

as the volumes used in 0D DymoDat model in Fig. 3 (left). The energy, current, voltage of the arc source parameters are taken to be the same as those used in 0D DymoDat calculation. In the present CFD simulation, the arc source is located in the center of the rectifier device, i.e. 1.4 m from the floor and 1.0 m from the wall on the transformer side.

In this preliminary design stage, the explosion vents in the present CFD simulation are modelled as fly-away type, circular burst discs with the pressure relief area of each circular disc = 1 m^2. Thus, there are 8 (eight) circular burst discs installed on the roof and on the back side of the container, making up a total of effective / net-relief area of 8 m^2. The burst disc has a pressure threshold of 0.1 bars and moves at approximately 50 m/s during explosion. It is important to note that in the present 3D-Prias module, the kinetics burst mechanism (e.g. mass inertia effects) of the burst disc is properly taken into account.

The distribution of the pressure acting on the container walls resulting from 3D-Prias / CFD simulation is shown in Figs 5-6 (front, back, top and bottom views). The pressure distribution shown in Figs 5-6 is obtained for t = 0.06 s, where the overall pressure reaches its peak.

It can be observed in Figs 5-6 that the pressure can be relatively high in some area of the container surfaces, particularly on the floor panel, on the lower part of the back wall (transformer-side) and on the main door, since these panels are directly exposed to the present arc pressure source.

Figs 7-8 depicts the distribution of the gas velocity during the pressure peak (t = 0.06 s) obtained from 3D-Prias / CFD simulation. The high velocity zone in the centre of the rectifier device in Fig. 7 (left) indicates the location of the arc pressure source.

The evolutions of the average and maximum pressure increase on the surfaces of the container are shown in Figs 9-10, respectively: it can be seen that the highest pressure build-up is observed for the main door and the container base floor (c.f. Figs 5-6). These pressure distributions will be applied on the container surfaces as inputs for the finite element (FE) structural analysis.

Conclusion

New rectifier designs need to have pressure relief devices, which take account of the latest arc flash energy calculations and arc pressure simulation. Already installed rectifier stations need to be reviewed and can be upgraded.

Remote supervision of all routine monitoring should be implemented.

Trending of operation parameters can be installed in the HMI systems to detect changes in the parameters before alarm or trip levels are reached.

Considering today's knowledge, new ways of designing and operating rectifier stations need to be implemented.

Authors

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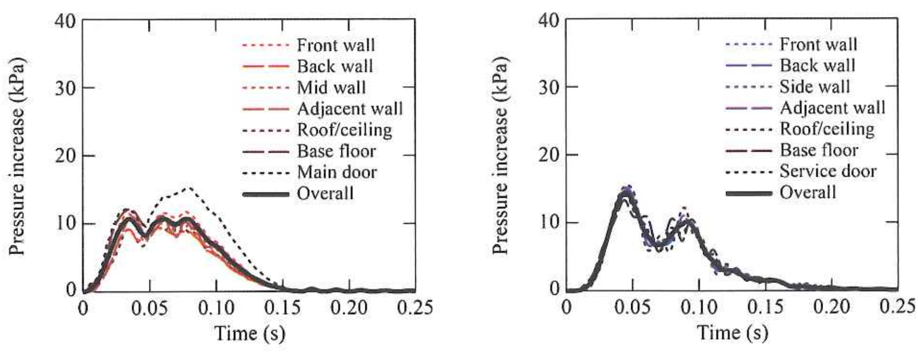

Figs 9-10: The average pressure increase on the surfaces of the main room (left) and of the service room (right) resulting from 3D-Prias / CFD simulation