

PRIMARY

1650VDC Smelter rectifier, passes an important milestone

As the number of pots and current densities increase in aluminium smelters the limit has been the capacity of the fuses and diodes to protect the rectifiers. ABB have successfully tested these components to 1810V AC, some 10% above their normal operating range.

By Max Wiestner*, Christian Winter** & Raffael Schnell***

For some time now, potline technology suppliers have asked 'What is the rectifiers voltage limit?' For a long time 1200V DC seemed to be the limit, then it became 1500V DC and now Sohar Aluminium Company (SAC) is setting a new level of 1650V DC at its smelter presently under construction in Oman. With 360 AP35 pots and a maximum operating voltage of 1650V DC, this is a new level for smelters. Increasing current has not been critical for some time but the voltages were limited by the availability of suitable fuses. The Oman grid configuration made it a requirement that in addition, +/-10% voltage variations needed to be allowed for considering all possible operation conditions.

Going to these high voltages, it was appropriate for ABB to conduct a Fuse – Semiconductor type test to ensure that the components installed at SAC will be fit for the intended purpose.

FUSE TESTS

Type test results from fuse suppliers do not consider the rectifier geometries and the impedances when a semiconductor fails. It is therefore important to conduct such test's on a true replicate of the rectifier.

The type test for the largest rectifier arrangement built to date, 103kA/111kA at 1650VDC, was performed in early May, 2006 in ABB's high power testing laboratory, (approved by Swiss Test).

Testing was performed in ABB's underground test installation using an original ABB rectifier cross-section assembly equipped with one fuse and one semiconductor (**Fig 1**). Calibration measurements were performed for verification of the short circuit current prior to the tests using a high current shunt (**Fig 2**).

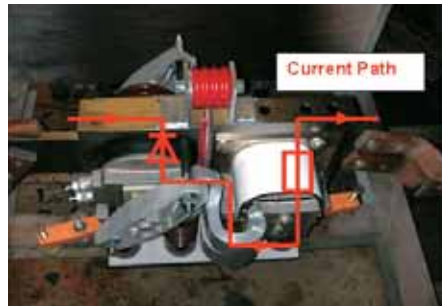
Two kinds of tests are applied to the semiconductor-fuse combination:

- Maximal breaking test (MBT)
- Maximal energy test (MET)

Three tests according to MBT and three according to MET criteria were performed.

The tests are based on the IEC 60269-4 standard. The test is only considered

successful if three consecutive tests fail to destroy the fuse. Pass criteria for the fuse allows small cracks on the fuse body but the body must remain in one piece and no plasma creep-out is accepted. On the semiconductor flange, small holes are allowed but no plasma is allowed to be released.



1 Test rack equipped with fuse. Current path shown in red

The current for the MET test is calculated by the fuse supplier, the current for the MBT test is the maximum available current (laboratory limitation).

FUSES FOR SMELTER RECTIFIERS

During 1997 and 1998, ABB made a large number of breaking capacity tests on smelter grade fuses. The conclusion was that the electromagnetic characteristic of the rectifier design can influence the fault clearing performance of the fuse. **Fig 3** shows fuses after one of the tests was performed. A total of 20 test shots were performed during the two day testing period.

SEMICONDUCTOR ASSEMBLY

Diode Failure Preparation: The diode has a diameter of 75mm (3"). The blocking

voltage is 5000V. For the test application, the diodes are prepared by purposely damaging the wafer during manufacture and assembly process in order to replicate a real failure mode. By damaging the wafer, the breakthrough voltage of the diode is reduced to approximately 100V. *External Protection Ring:* ABB's rectifier



2 High current shunt for calibration measurement

design includes an external protection ring which prevents plasma arcing damaging the rectifier.

Plasma Containment Ring: In addition, a plasma containment ring was installed to prevent damage to the rectifier DC heat-sink or the semiconductor cooling box through plasma leakage.

DIODES FOR LARGE RECTIFIERS

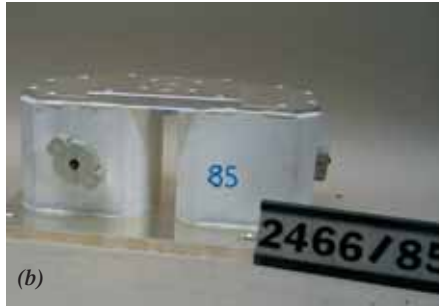
Large rectifiers such as for aluminium smelters pose strict requirements for the semiconductor devices thus low conduction losses and ever higher blocking voltages are required. The enormous rectifier current requires parallel connection of the diodes. To ensure homogenous current sharing and thus avoid overloading of single diodes,

Test designation	Max Breaking Test (MBT)	Max Energy Test (MET)
No of Tests	3	3
Recovery voltage [Vtms]	1697	1697
Prospective current [kA]	190	95
Power factor [1]	0.1-0.2	0.1-0.2
Making angle after voltage zero [°]	n/a	0-20
Initiation of arcing after voltage zero [°]	65-90	n/a

Table 1 Test specifications

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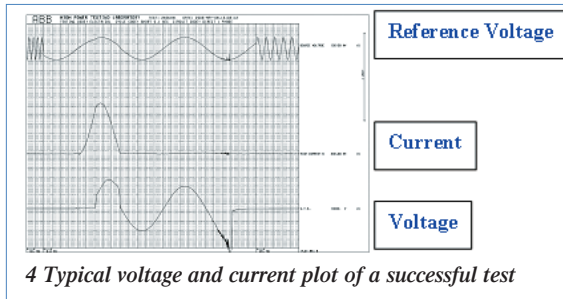
3 Bussmann (a) and Ferraz fuses (b) after one test

the conduction voltage drop of the diodes needs to be matched in narrow bands – of typically 50-100mV.

It is very rare, but statistically unavoidable, for diodes to fail for instance due to strong network disturbances. In such a failure case the behaviour of the diode should be known and therefore characterised.

Simplified rectifier diode failures can be divided into two categories:

- Current overloading during conduction: In such a case, also known as surge current, a sudden rise in current causes the destruction of the diode wafer but is not regarded as critical with respect to rupture of the diode housing. Even if the diode fails the whole wafer is in a forward direction and can carry a part of the current. Therefore the energy of the fault current is dissipated over a large area.
- Blocking voltage failure: If the rated diode voltage is exceeded the diode will fail. In such a case the failure spot is very local and the energy of the fault current is dissipated in a very small area. This causes a huge temperature increase that melts the silicon and the surrounding parts and causes a strong



shock wave with plasma. For ABB diodes this usually happens in the bulk of the wafer where the failure location is protected with the massive copper plugs. Nevertheless it cannot be completely excluded that the failure spot is on the unprotected wafer periphery. If this happens the failure causes an arc that can burn holes in the diode housing or even worse, cause the ceramic to crack if no counter measures are taken.

ABB diodes are designed to prevent the ceramic cracking up to high I^2t values thus preventing flying particles of ceramic debris with high kinetic energies posing severe risks. With a suitable fuse coordination and rectifier design the risk of burning holes in the diode housing can be minimised but not always completely

avoided. Therefore it is possible that soot and small amounts of plasma can contaminate the cooler and make diode replacement inconvenient. To overcome this, ABB diodes can be shipped with a protective ring that has proven to successfully protect the cooler from contamination even in severe failure events.

PREPARATION OF THE DIODES

For explosion rating tests of the rectifier the diodes have to be prepared to simulate

the worst-case failure mode. As mentioned before, this is the case if a blocking failure occurs on the wafer periphery. Preparation involves purposely making a small mechanical damage on the wafer edge and thus reducing the diode blocking voltage below 100V. That ensures a very local flow of the fault current on the most critical location with

regard to diode explosion.

CONCLUSION OF TEST RESULTS

The tests were very successful. Even with a significantly higher voltage of 1784V AC (rms), (representing a DC voltage of 1900VDC), the fuses selected passed the more strenuous Maximal Energy Test (MET). The fuses only failed at 1810V AC (rms).

With the newly designed diode protection systems implemented and the fuse stressed way above its rating, damage to the rectifier would be minimal and repair works would only take a few hours.

With the Fuse-Semiconductor type test performed in early May 2006, ABB has proved that the selected fuses and semiconductors for the Sohar Aluminium project have been correctly rated. ■

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