Gotthard tunnel’s power semiconductors give insights to IGCT reliability

Following completion of Switzerland’s Gotthard Base Tunnel, a medium voltage drive was decommissioned and the parameters of its IGCT (integrated gate-commutated thyristor) power semiconductors compared with the original production data 15 years ago. The results offer a fascinating insight into the robustness of the ABB devices.

At 57 kilometers the Gotthard Base Tunnel is the world’s longest railroad tunnel, connecting northern and southern Switzerland. In addition to increasing freight capacity along the Rotterdam-Basel-Genoa corridor, the tunnel includes regular passenger services that significantly cut travel time from north to south.

During its construction, excavated gravel was transferred to either entrance and to a central portal. The central portal in Sedrun featured an elevator, which carried the material, some 850 meters (m) to the surface (see figure 2). During the 14 years of construction, the elevator carried out more than 84,000 lifts, removing 28,200,000 tons of gravel.

The elevator’s motor was speed controlled with an ABB medium voltage drive that used ABB’s IGCT power semiconductor switches.

Analysis of IGCT power semiconductors
Following completion of the tunnel, the medium voltage drive was decommissioned. The IGCTs were returned to ABB’s semiconductor facility for an in-depth analysis. Their electrical parameters were remeasured and compared with the original production measurements of 15 years earlier. No significant shift or degradation of the electrical parameters were found. The hermetic ceramic housing of the power semiconductor was still perfectly sealed.

The device analysis focused on the turn-off circuit involving the gate unit and the parallel connection of electrolytic capacitors and MOSFETs (metal-oxide-semiconductor field-effect transistor). Original gate impedance measurements from the device qualification were compared against devices of different ages that were either in operation (including the ‘Gotthard devices’) or held in storage. Here, again, no significant degradation of the gate circuit impedance was found (see figure 3).
When the elevator was lifting gravel to the surface, the silicon chips have been exposed to heavy load cycles due to rapidly heating up during acceleration phase, and fast cooling down after the lift stopped for loading or unloading. Therefore, a detailed examination of mechanical wear-out of the device’s construction was carried out. Traces of wear-out were found but the degradation was low. As an example, the degradation of the cathode metallization is shown in figure 6.

Motivation for this analysis
Since the first commercial IGCT device application in 1997, more than 250,000 units have been installed. The majority are still operating in demanding and reliability-critical applications like medium voltage drives, interties, breakers, FACTS and others.

The operation principle of the IGCT requires during turn-off the full load current to be commutated to the gate path through the gate unit. While this allows the safe and rugged turn-off, it also requires a powerful and reliable gate unit that takes the full phase current for certain micro seconds (see also figure 7). This feature led to animated discussions when the product was launched.

Often the massive need of parallel connected (several tenth) electrolytic capacitors and MOSFETs in the turn-off circuit were predicted as potential reliability issues in the technical community, although this aspect was thoroughly accounted during the development phase. Furthermore, the field failure return analysis has clearly proven highest reliability of the IGCT: the overall failure rate of below 100 FIT (failed devices in 10^9 operating hours) is state-of-the-art for power semiconductor devices. Additionally, the root cause analysis indicates no issue with the gate unit.

This overall picture has been successfully confirmed by the investigation on the IGCT devices from the Gotthard Base Tunnel elevator.