The strongest link

Captive power plant-smelter interface for increased power plant efficiency

As aluminum smelters use vast quantities of electricity in the electrolysis of alumina and carbon, it makes sense to build them where electrical power is available at a reasonable price. Generating utilities like to have smelters on their grids as they provide stable clean loads. However, with increasing power demand, utilities are finding that they can no longer feed today’s smelters from the grid and therefore co-generation is required. This means dedicated or “captive” power plants are now being built close to the smelter to supply it with the required power. But what if a smelter is located in a remote area where there is a weak or even no utility grid? Finding ways of successfully interfacing the power plant and the smelter has become somewhat of a challenge. The key to finding the most optimal interface solution involves meeting the requirements of both, and many of these are outlined in the following article.

Smelter potline power ratings have reached 600 MW and utilities are under increasing pressure to meet the grid requirements of many smelter owners. The solution for many owners has been to install “captive” power plants. However, new smelter projects, with or without captive power plants, are often located in weak power grid locations, and interfacing the smelter and the power plant to ensure adequate power requirements are met is a very challenging task. Many issues such as power demand and fluctuations, power quality, potline start-up and trip need to be considered. Other critical issues include the power plant efficiency during normal operation or the consequences of a generation unit trip when it is in island operation mode. It is also important to note that load shedding with a diode rectifier only occurs at a maximum rate of 5 MW/3 seconds.

Many smelter owners are now installing “captive” power plants because of the pressure utilities are under to meet the grid requirements of many aluminum smelters.

Meeting the requirements from both the smelter and power plant sides, as outlined in the Factbox, is key to finding the most optimal interface solution, which needs to be found very early in the project planning stage. In the long run, early optimization of the project design may reduce the capital investment cost of the power plant and smelter substation. An ABB develop-
The power plant must be able to cope with the following smelter issues:
- Power swings: Daily anode effects create a sharp 15 MW power swing.
- The potline may trip more than 5 times in the first year (forcing a 600 MW immediate drop).
- The potline initial start-up power demand increases by 3.5 MW/day.
- A potline ramp-up of 20 MW/min is the preferred restart rate after a trip.
- A power factor of 0.82 is required for a short time during restart.
- The voltage drops to 70 percent on the smelter bus when rectifiers are energized without synchronizing the feeder breakers.
- The higher the SCC, the lower the required efforts to meet power quality demands.
- If the maximum allowable THD is two percent, smelter tertiary filters are required if the SCC is less than ten times the smelter rating.

In the overall system design, the following smelter/power plant parameters must be considered:
- Is island operation required? If yes, a detailed study containing information about power flow, power quality and transient stability is needed.
- Diode rectifiers can only shed their load at a maximum rate of 5 MW/3 sec.

The power plant must be able to address the power plant if the demands of the smelter substation are to be met. In particular, parameters that need to be defined include:
- Short Circuit Capacity (SCC) for all power plant operation conditions.
- The maximum allowable Total Harmonic Distortion (THD).
- Maximum possible power swings and rate (in MW).
- Maximum reactive/active power swing.
- The maximum allowable harmonic current loading of the cables.
- The power factor required.
- Maximum power (delta versus phase) unbalance.

Other points the power plant needs to consider include:
- Voltage dips are to be expected and allowed.
- Grid codes must be complied with.
- Second order harmonic current loading as large transformers are being energized.
- A generator synchronizing procedure and minimal block load must be specified.
- The variation in grid and island operation SCC is available on the smelter HV substation busbar.

The following points show interface issues that must be addressed to the power plant if the demands of the smelter substation are to be met. In particular, parameters that need to be defined include:
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Footnote
  ^ IEEE 519 is the international standard that describes acceptable limits of harmonics in electrical systems.

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^ Information concerning ABB’s Blackout Protection Control (BPC) is proprietary and will only be made available at a later stage.

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The following five case studies of captive or semi-captive smelters illustrate the wide variety of overall system designs and complexities that can be achieved. For these projects, ABB either supplied equipment or performed system studies.

**ALBA, Bahrain**
In recent years, Aluminium Bahrain (ALBA) experienced some blackouts that were attributed to a variety of reasons. Due to the mix in generation and five potlines, the de-energizing or re-energizing of the potlines is not so critical as load drops are smaller and can be shared by a high number of generating units. Therefore ALBA’s operation mode is such that the smelter auxiliary consumers are operated on different grids to the smelter potlines, thus making the system immune to voltage dips or load drops.

**DUBAL, Dubai**
Dubai Aluminum (DUBAL) has a large number of potlines. Some are rated at less than 100 MW and have a good mix of generation. Therefore the grid can easily compensate should one potline trip. In addition, the large number of potlines as well as their low power rating have an easier effect on the power quality level, as the harmonic currents are compensated for with a multi-pulse operation. Start-up power demand and load rejection are of no concern, and auxiliaries are fed from a different grid supply.

**Nordural, Iceland**
The Icelandic grid is becoming increasingly stronger. However, most of the power generated comes from low inertia geothermal steam turbines and from the non-industrial power demand fluctuations between day and night. Aluminum smelters create an ideal load. The large daily change in grid stability requires a very flexible smelter substation design to allow for high-speed load shedding and the highest power quality performance. Due to this requirement, Nordural decided to use tertiary filters on the regulation transformers as well as thyristor rectifiers for high-speed load shedding. The highest power quality has been achieved by control switching the rectifiers as well as the tertiary filters.

**Fjardaal, Iceland**
This single 500 MW potline smelter will be fed from a captive hydro power plant is located approximately 60 km away. A weak 132 kV grid inter-connection is possible at the power plant substation. The auxiliary power for the smelter will be taken from the same power lines feeding the smelter rectifiers. Should the potline trip, the power plant will need to be idled because the Icelandic grid will not be able to take the extra power. The available SCC has to be considered low to very low during initial start-up and normal operation.

**Sohar, Oman**
This new smelter is designed to accommodate up to three 550 MW potlines and is fed from a captive combined cycle power plant. A 220 kV grid inter-connection is possible at the power plant substation and the distance between the power plant and the smelter is approximately 12 km. The auxiliary power for the smelter will be taken from the same power lines feeding the smelter rectifiers. As in the previous case study, if the potline trips, the power plant will need to be idled, and the available SCC must be considered low to very low during initial start-up and normal operation.
Final thoughts

With an available SCC of 2500 MVA from a power plant and a 600 MW smelter load, the corresponding ratio of four represents a very weak system – a ratio of 10 or higher is preferable. It is therefore estimated that if one gas turbine were to trip at the power plant this would in turn trip the smelter. Diode rectifier systems cannot shed loads, and island operated Gas turbine (GT) power plants may trip on under-frequency in less than two seconds. To avoid this, a “dummy” load may be required, which would protect the power plant from being completely disconnected in the event of a potline trip, and allow the smelter to start. There are two possible ways to protect the smelter from tripping after a GT trip: ■ The power plant is designed such that the smelter load ramp and trip can be followed (ie, using ABB’s BPC). ■ The smelter is equipped with thyristor rectifiers which allow immediate load shedding.

The key to finding the most optimal interface solution between a power plant and a smelter involves meeting the requirements of both.

If a total harmonic distortion (THD) of two percent or power factor correction to 0.98 is required, and the power contract is such that a high power factor is always needed, then harmonic current filters connected to the regulating transformer tertiary is the most economical method. This method is also required if the power system is weak. Synchronized switching should be used on the filter banks to reduce inrush current stress and over-voltages. Nordural’s (Iceland) new converter station is the most advanced in this respect with:

■ A full range regulation transformer with tertiary filters, which always allows for the most optimal power factor
■ Thyristor rectifiers that follow the grid power capabilities
■ Synchronized switching of transformers and filters for (a) minimal network distortion in a very weak grid and (b) minimal stress on filters, switchgear and transformers.

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Reference publications
■ Metal Events Conference, Reykjavik Iceland 2004
■ Metal Bulletin Conference, Oslo Norway 2004
■ Metal Events Conference, Muscat Oman 2005
■ Aluminium World, Bahrain Feature 2006/1
■ Metal Events Conference, Dubai UAE 2006