The strongest link

Captive power plant-smelter interface for increased power plant efficiency

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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-

Factbox Power plant and smelter requirements

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:
- 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 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 dips to 70 percent on the smelter bus when rectiformers 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 rectiformers can only shed their load at a maximum rate of 5 MW/3 sec.
- Synchronized switching of transformers reduces power disturbances and voltage dips as well as mechanical stress on rectiformers and harmonic current filters. In any case the island mode of operation may not be possible without synchronized switching.
- GIS or AIS breakers must be able to switch between phases with an accuracy of ±1 ms.
- To comply with the international standard IEEE 519[2], tertiary filters are required for the rectiformers in island mode.
- Harmonic current filters on the high voltage (HV) side may need to be studied as they are loaded with the harmonic currents, which may be in the grid.
- Power plant control systems need to be able to generate and send a high-speed load-drop signal.

Footnote

[2] IEEE 519 is the international standard that describes acceptable limits of harmonics in electrical systems.

ment known as Blackout Protection Control (BPC)[1] also plays a critical role in ensuring stable smelter operation.

1 shows typical smelter voltage and current load curves that are seen by the power plant and which have to be considered in the overall system design. 2 shows the load that the smelter substation can shed with and without ABB's BPC. The diagram in 3 shows the smelter substation power quality versus the strength of the feeding grid. This must be considered should the grid be disconnected and for island operation to continue. Some of the big smelter power consumers, such as the Uninterruptible Power Supply (UPS), inverters and AC drives, are very susceptible to high harmonic current distortions. In 4, the power factor of a smelter during initial start-up is shown. This same power factor also applies after a potline restart. The design of the rectifier needs to be selected based on the power supply agreement as well as the power quality during such operations.

Voltage drops during rectiformer energizing

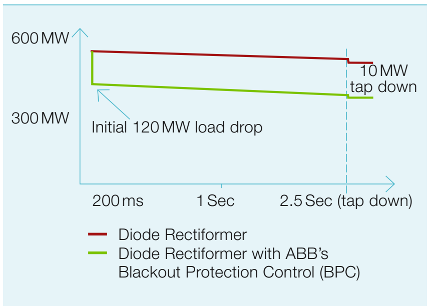
Within captive power plant smelter systems, there may be some operation scenarios where the power plant feeds the smelter in island operation. During these scenarios, the available SCC may be considerably reduced. As rectiformers become ever larger for these large smelters, their impact on the network during energizing is in turn quite substantial. 6 shows this impact with and without controlled energizing. The voltage dips may result in the tripping of already energized consumers, and may be very critical for captive power plant smelter projects. To be more specific, the medium voltage value may drop by up to 25 percent of the nominal rating, which is way beyond the allowed value of 10 percent.

1 Active power demand during potline trip and start-up

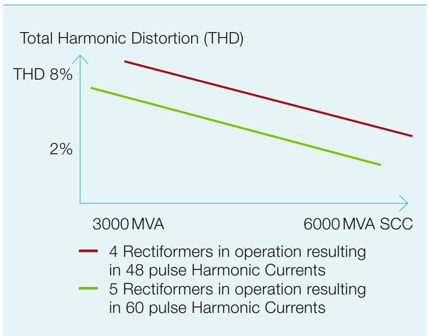
Footnote

[1] Information concerning ABB's Blackout Protection Control (BPC) is proprietary and will only be made available at a later stage.

2 Load shedding capabilities of a smelter substation with and without ABB's Blackout Protection Control (BPC)



3 Power quality versus grid power strength



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.

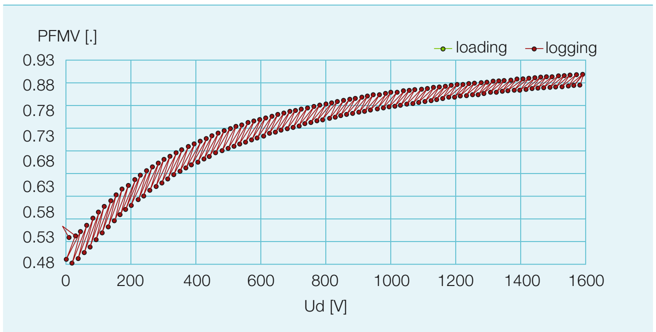
DUBAL, Dubai

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.

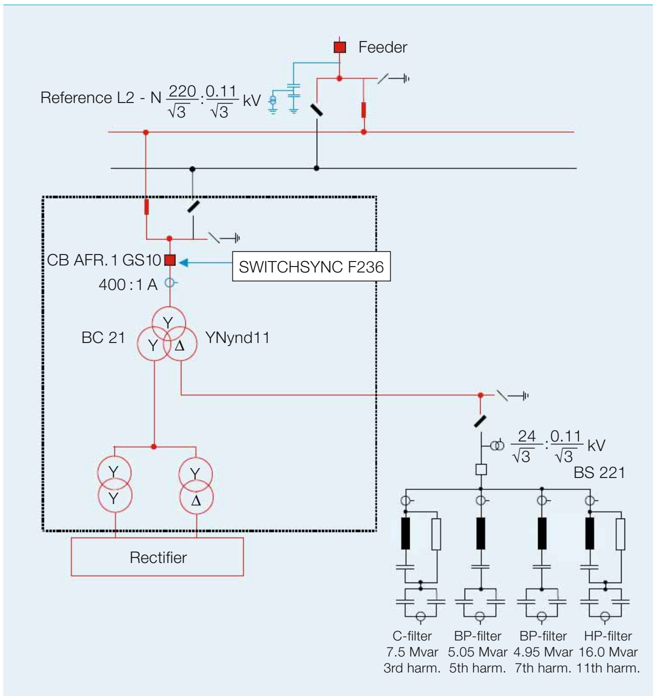
Nordural, Iceland

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 rectiformers for high-speed load shedding. The highest power quality has been achieved by control switching the rectiformers as well as the tertiary filters 5.

4 Power factor during potline start-up



5 Switch synchronization at the Nordural (Iceland) plant



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 rectiformers. Should the potline trip, the power plant will 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 rectiformers. 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

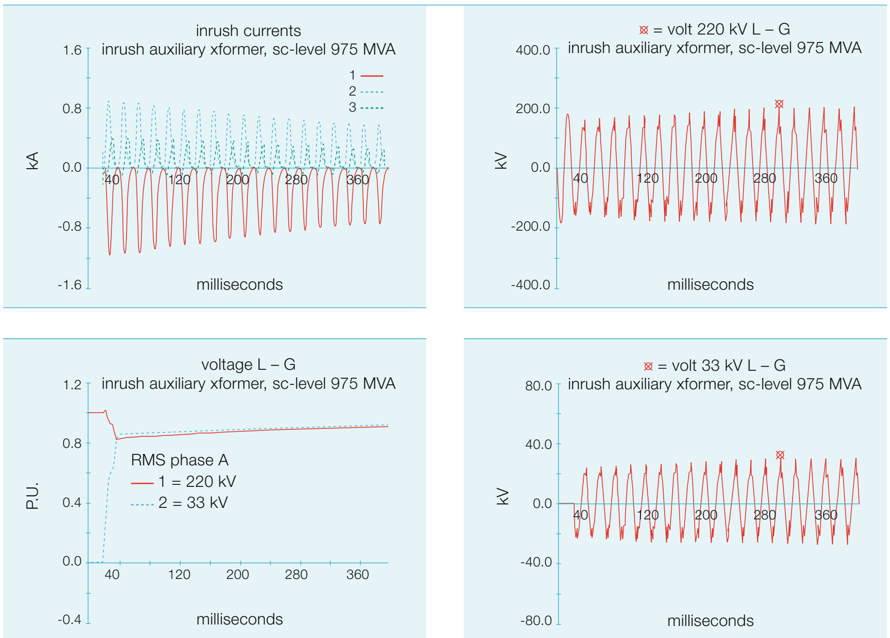
With an available SCC of 2500 MVA from a power plant and a 600 MW smelter load, the corresponding ratio of four represents a very weak system – a ratio of 10 or higher is preferable. It is therefore estimated that if one gas turbine were to trip at the power plant this would in turn trip the smelter. 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.

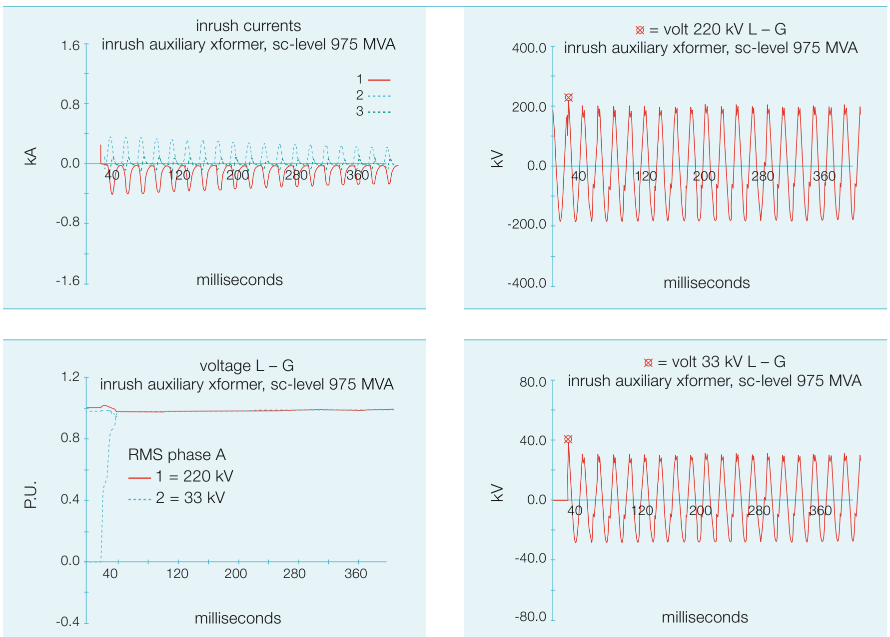
The key to finding the most optimal interface solution between a power plant and a smelter involves meeting the requirements of both.

6 Voltage dips on the medium voltage power energizing transformers, with and without controlled switching

a Inrush regulating transformer



b Inrush regulating transformer with synchronized closing



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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