Captive power plant – smelter interface with blackout protection for increased power plant efficiency

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Smelter potline power ratings have reached 600 MW, but new smelter projects with or without captive power plants are often located in weak power grid locations. It has become very important to develop an overall concept for the interface between the power plant and the smelter substation, and this needs to be done at a very early stage of project planning. Early optimisation of the project design may reduce the capital investment cost of the power plant and smelter substation.

When considering the smelter – power plant interface, many issues come up and need to be taken into account, such as power demand and fluctuations, power quality, potline start-up and potline trip. Other critical issues are the power plant efficiency during normal operation or what happens if one of the generator units trips during the so-termed island operation mode. Here, ABB's blackout protection control plays a critical role for the smelter's operational stability since a smelter requires a stable power supply whereas load shedding with a diode rectifier is only possible with a slow ramp.

Various requirements relating to the power plant and smelter

The points below show power plant interface characteristics which should be demanded from or explained to the power plant as parameters required by the smelter substation.

- SCC (Short Circuit Capacity) for all power plant operation conditions
- Maximum permissible THD (Total Harmonic Distortion) by power plant or grid
- Maximum power swings and possible rate, in MW Maximum reactive – active power swing
- Maximum permissible harmonic current loading of cables
- Voltage dips to be expected and allowed
- Power factor required
- Grid codes to be complied with
- Maximum 2nd-harmonic current loading while transformers are energised
- Maximum power (delta u-phase) unbalance
- Explain the process of generator synchronising and the minimum block load
- Explain the characteristics of grid and Island operation (start-up SCC)
- High speed signal must be available to warn of load decrease

Smelter information to the power plant

The points below list various smelter characteristics which the power plant must be able to provide or cope with:

- Power swings: daily anode effects create a sharp 15 MW power swing
- Potline may trip more than 5 times in the first year (600 MW immediate drop)
- Potline initial start up power demand increases by 3.5 MW/day
- Potline restart after tripping: 20 MW per min ramp-up preferred
- Power factor 0.82 during restart for a short time
- Voltage dip to 70% on the smelter bus when rectiformers are energised without synchronisation of the feeder breakers, if 5 x SCC compared with the transformer rating
- The higher the SCC, the less effort is required to meet power quality demands
- If the maximum permissible THD is 2%, smelter tertiary filters are required if SCC is 10 x smelter rating.

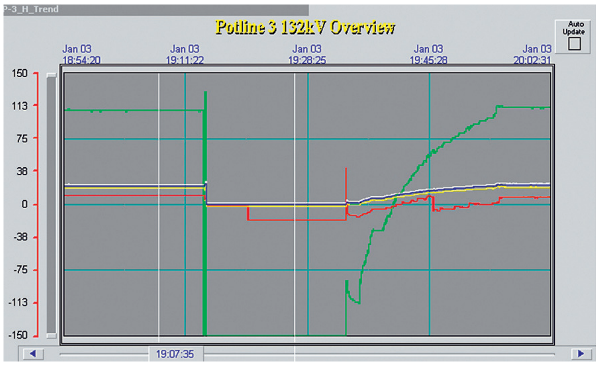
Interface parameters to be considered

The points below show what smelter power plant parameters should be considered in the overall system design:

- Is island operation required? If yes, a detailed study is needed
- Diode rectiformers cannot shed load quickly; the maximum is 5 MW / 3 sec
- Synchronised switching of transformers reduces power disturbances and voltage dips as well as mechanical stress on rectiformers and harmonic current filters
- Without synchronised switching, the island mode of operating may not be possible
- GIS or AIS breakers need to be able to switch with +/- 1 ms accuracy between phases
- IEEE 519 (power quality guideline) can only be met with tertiary filters on the rectiformers in island mode
- Harmonic current filters on the HV side may be critical and need to be studied as they get loaded with harmonic currents which may be flowing in the grid
- The power plant control systems must be able to generate and send a high speed load drop signal

Load rejection of the smelter – one of the most critical design issues

The graph below shows the smelter voltage and current load curves which will be seen by the power plant and have to be considered in the overall system design.

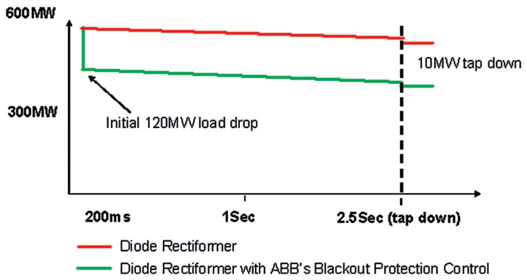


Smelter voltage and current load curves

Load shedding capabilities of a smelter substation

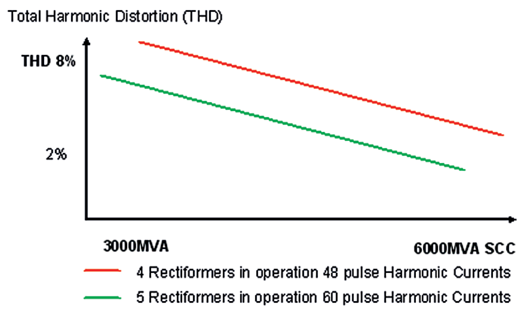
The diagram below shows the load that the smelter substation can shed, with and without ABB's blackout protection.

The detailed design information about ABB's Blackout Protection Control (BPC) proprietary and will be made available during the project stage.



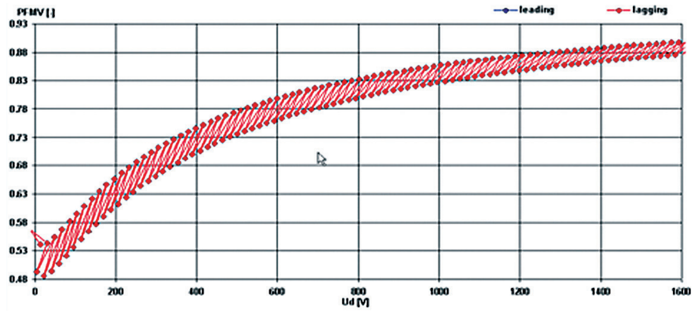
Power quality vs. grid power strength

The diagram below shows the smelter substation power quality versus the strength of the feeding grid. This is, in particular, to be considered should the grid be disconnected and island operation continued. Some of the smelter power consumers, such as UPS, inverters and AC drives, are very susceptible to high harmonic current distortions.



Power factor during start-up of the smelter

The following graph shows the power factor of a smelter during start-up. This power factor applies for the initial start-up as well as after a potline restart. The design of the rectifier needs to be selected on the basis of the power supply agreement, as well as the power quality during such operational points.



Voltage dips during the energising of rectiformers

In captive power plant smelter systems there may be some operation scenarios in which the power plant feeds the smelter in island operation. During such operation, the available short circuit capacity may be considerably reduced. As rectiformers become ever larger for these large smelters, their impact on the network during energising is very large. The diagram below shows the impact with and without controlled energising (see Nordural Iceland start-up publication) The voltage dips may result in tripping of already energised consumers. Such voltage drops may be very critical for captive power plant smelter projects. This is because the voltage on the MV may drop by up to 25% of the nominal rating, which is far beyond the normally permitted value of 10%.

Case study ALBA, Bahrain

Aluminium Bahrain (ALBA) has had some blackouts during recent years of operation. Due to the mix in generation and with its 5 potlines, the de-energising of a potline is not so critical. ALBA's operation modes, however, are such that the smelter auxiliary consumers are operated on different grids from the smelter potlines, making the system very immune to voltage dips or load drops.

Case study DUBAL, Dubai

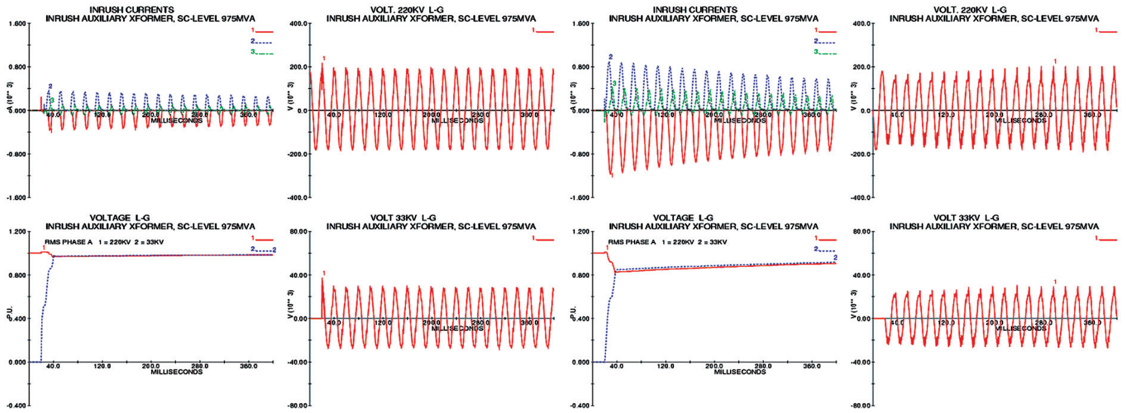
Dubai Aluminium (DUBAL) has a very large numbers of potlines, some of them rated at less that 100 MW, as well as a good power generation mix. The grid can easily compensate should one pot line trip. The large number of potlines as well as their low rating also eases the demands relating to power quality as the harmonic currents are compensated by the multi-pulse operation. Start-up power demand and load rejection are of no concern. Auxiliaries are fed from a different grid supply

Case study Nordural, Iceland

Although the Icelandic grid is becoming increasingly powerful, most power generation originates from low-inertia geothermal steam turbines, and non-industrial power demand fluctuates from day to night by more than half. Aluminium smelters create an ideal load. The very large daily change of grid stability demands a very flexible smelter substation design to allow for high speed load shedding and highest power quality performance. Due to this requirement, Nordural chose to use tertiary filters on the regulations transformers as well as thyristor rectiformers for high speed load shedding.

Case study Fjardaal, Iceland

This single 500 MW potline smelter will be fed from a captive hydro power plant. A weak 132 kV grid inter-connection is possible at the power plant substation. The distance between the power plant and the smelter is approx. 60 km. The auxiliary power for the smelter will be taken from the same power lines that feed the smelter rectiformers. Should the potline trip, the power plant will need to be idled as the Icelandic grid would not be able to take the power. The available short circuit capacity is rated as low to very

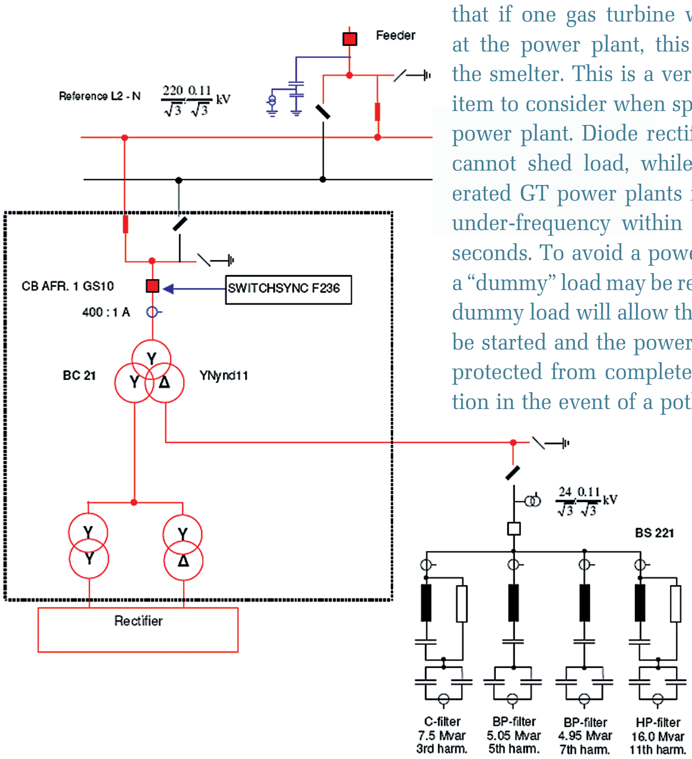


Voltage dips on the MV power energising large transformers, with and without controlled switching

low during initial start up and normal operation.

Case study Sohar, Oman

This new smelter design is for up to three 550 MW potlines, fed from a captive combined cycle power plant. A 220 kV grid inter-connection is possible at the power plant substation. The distance between the power plant and the smelter is approx. 12 km. The auxiliary power for the smelter will be taken from the same power lines that feed the smelter rectiformers. Should the potline trip, the power plant will need to be idled as the Omani grid would not be able to take the power. The available short circuit capacity is rated as low to very low during initial start up and normal operation.



The best power quality was achieved by the installation of controlled switching of the rectiformers, as well as of the tertiary filters

Summary

With an available short circuit of 2500 MVA from a power plant and a 600 MW smelter load, the ratio of 2500/600 = 4 represents a very weak system. In such a case, it is estimated that if one gas turbine were to trip at the power plant, this would trip the smelter. This is a very important item to consider when specifying the power plant. Diode rectifier systems cannot shed load, while island operated GT power plants may trip on under-frequency within less than 2 seconds. To avoid a power plant trip a "dummy" load may be required. The dummy load will allow the smelter to be started and the power plant to be protected from complete disconnection in the event of a potline trip. To protect the smelter from tripping after a GT trip, there are two options: the power plant can be designed such that the smelter load ramp and trip can be followed (ABB's BPC), or the smelter has thyristor rectifiers which allow immediate load shedding.

If a THD of 2% or a power factor correction to 0.98 are required, and the power contract is such that a high power factor is always required, 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. Synchronised switching should be used on the filter banks to reduce inrush current stress and voltage surges. Nordural's new conversion station in Iceland is the most advanced in this respect with:

- full-range regulation transformer with tertiary filters, giving an optimum power factor at all times
- thyristor rectifiers to follow the grid power capabilities
- synchronised switching of transformers and filters for minimal network distortion, in a very weak grid, and minimal stress on filters switchgear and transformers.

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