Reprint from Aluminium World 2009, Volume 1

Preserving power quality for cost effective smelter power consumption

Harmonic currents create electrical losses and if not compensated create costs for additional electrical power. The investment in a compensation system is repaid very quickly. ABB has the know-how and solutions.

Power and productivity
for a better world™

Preserving Power Quality for Cost Effective Smelter Power Consumption

ABB Switzerland Ltd.

Harmonic currents create electrical losses and if not compensated create additional electrical power costs. The cost of investing in a compensation system is repaid very quickly. By Max Wiestner, Industry Manager Primary Aluminium and Christian Winter, Chief System Engineer Rectiformers, ABB Switzerland and Reto Schraner, Chief Commissioning Engineer, Sohar Aluminium project.

Electrical energy represents between 30 to 40% of total aluminium production costs. Power quality is assessed by the "harmonic currents" still in the feeding power grid after cleaning them up and the "power factor" when the smelter is running under normal conditions. In the case of a large two pot line smelter, at least one additional power generation unit would be required if no power factor and harmonic current compensation system had been installed. The investment cost for a compensation system, is far smaller than that required for an additional power generation unit and the cost of operating it.

Total Harmonic Distortion (THD)

THD is a measurable parameter that is used to evaluate power quality. The smelter AC/DC conversion system rectiformers, which convert the grid power (alternating current) to the DC power required by the pot rooms, create harmonic currents due the nature of the more than 100-year-old technology. These harmonic currents are created by the rectiformers when the DC current is transformed and they appear as high frequency currents on top of the normal current in figure 1.

These high frequency currents create electrical losses within all consuming devices if exposed to them. Low voltage motors for example will use up to 10% more electrical power if the power quality is very poor. With today's smelters with up to 1,200MW, this means that nearly one additional power generation unit will be required just to compensate for poor power quality, if not compensated by appropriate equipment.

Power Factor (PF)

PF is another measurable parameter used to evaluate power quality. The power factor is the difference between the power, (active power) used to produce aluminium and the power generated by the power plant, (apparent power). Some equipment within the smelter consumes 80% active power and creates 20% non-active (reactive) power. Naturally the idea is to have a very high power factor to minimise the power generation required.

Assuming a smelter requires 1,200MW and does not have any PF compensation, the power plant would require one additional generation unit just to produce the apparent power. Smelters therefore require systems that compensate for both harmonic current distortion and power factor displacement.

Generation of harmonic currents

Rectiformers unfortunately create harmonic currents with different frequencies. Within smelters these currents are reduced by the use of 12-pulse rectifier units which are designed in such a way that the total rectiformer station will have a 60-pulse displacement creating the least possible harmonic currents. When, however, a single pot line with a power

Figure 1: Shows typical harmonic currents

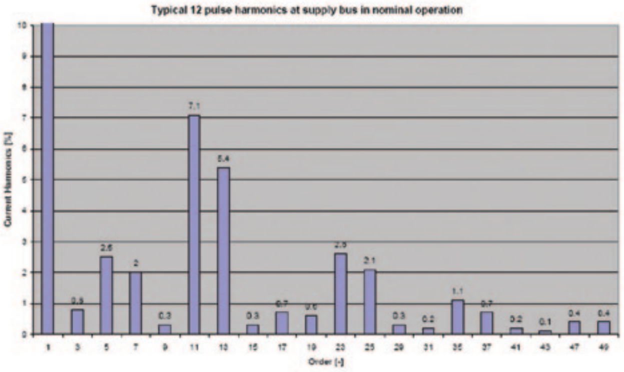
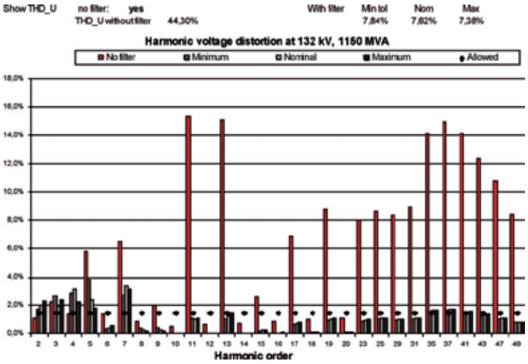


Figure 2: Shows harmonic currents in a low capacity grid



Reprinted from Aluminium World 2009 Volume 1
Published by Sovereign Publications

Figure 3: Shows harmonic currents in a high capacity grid

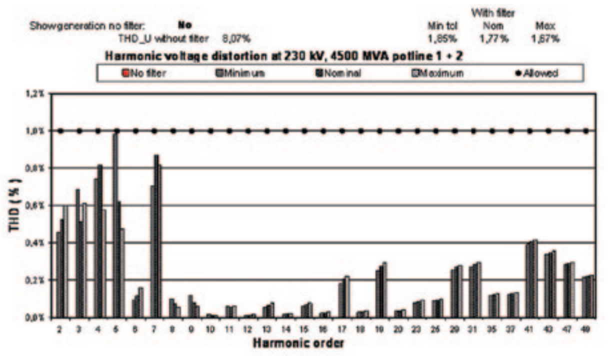


Figure 4: Power factor of smelter

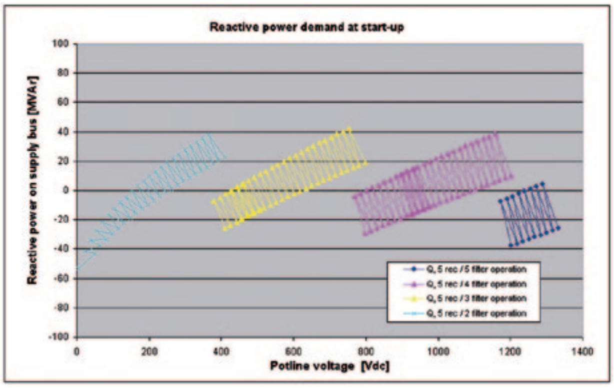


Figure 5: Shows a typical single line of a compensation system

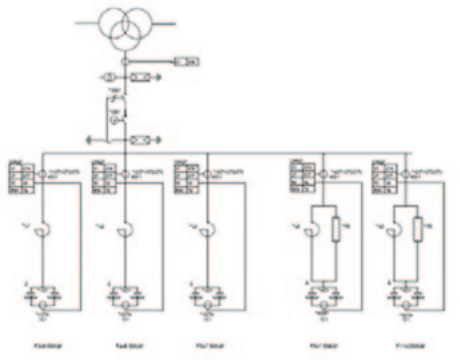


Figure 6: Medium voltage compensation

consumption of 600MW is operated in a low capacity grid they seriously affect power quality.

Figures 2 and 3 show the impact of low and high capacity grids. Capacity is taken to mean the strength of the power grid. This in turn depends on how many power plants are connected together and the power line size and length to the smelter.

Power factor of electrical consumers

A typical smelter motor consumes approximately 80% of active power and 20% non-active (reactive) power. If a new two pot line smelter only consisted of a motor and no compensation was installed, then five 240MW generation units producing the active power and a minimum of one 240MVA unit producing non-active power would be required. The smelter's main power consumers (the rectiformers) fortunately do not have as low a power factor as typical motors but they still require a large compensation system. At least 200-300MVA should be compensated per large pot line.

Combined THD and PF compensation

As it is not practical to have one additional generator unit producing the extra electrical power required due to non-compensated harmonic currents and another for power factor compensation, the obvious solution is to combine them. Typically such a system consists of reactors and capacitors, which are also used to compensate the power factor, and resistors to damp the tuned circuits to prevent resonances.

To compensate the majority of harmonic currents these systems are split up into two to five sub-systems tuned to compensate different harmonic currents. The different tuning depends on the design of the rectiformer substation and the feeding grid. Typical sub-systems, known as filter branches, are tuned to 3, 5, 7, and 11 times the normal frequency. This is 50 or 60 hertz.

Figure 7: High Voltage compensation system

Two different compensation system concepts are commonly used and need to be evaluated during the early design stage of the power conversion station. The turnkey cost of the two concepts both seem to work out cost neutral.

High power factor and power quality result in lower power plant investment and operation costs

Medium voltage (MV) compensation

A compensation system for a medium voltage (20-36kV) system, is connected to the regulation transformer tertiary winding. Latest designs are fitted with an MV circuit breaker to allow incremental compensation. With this solution each unit needs a compensation system capable of meeting performance limits, even if only four units are in operation. With this design, high power factors are also possible during the initial smelter start up and harmonic currents do not reach the high voltage level. An additional advantage is that they can be designed and installed without in-depth system studies of the feeding grid. This compensation system will not be impacted, or only marginally, by the power quality of the feeding grid.

High voltage (HV) compensation

High voltage (110-240kV) compensation systems are connected to the utility power grid via the high voltage switchgear. These compensation systems require a more in-depth study to analyse their impact on the feeding grid, in both directions, as the system will also possibly be loaded with existing harmonic currents from the utility grid. They are of a much simpler design and require a smaller footprint but their feeding switchgear needs to be rated to withstand high voltage surges during switching operation.

Design of high voltage systems needs to be based on the power contract limitation so that they can also meet the power factor requirements during initial start up. Their performance is more suitable for higher grid capacities as it is very costly to install multi-branch filters at higher voltages

High voltage design considerations

As these compensation systems operate at the utility level, high voltage systems have a direct impact on the grid and vice versa. Energising and de-energising of such compensation systems create a power quality disturbance of their own. These systems have an affect similar to when a power line is energised or de-energised and create very high voltages that can destroy components or circuit breakers. When high voltage compensation systems are being considered, the feeding/controlling switchgear needs to be capable of operating them. Figures 8 and 9 show the energising and de-energising of a 220kV compensation system with minimal power quality distortion. This is due to the use of ABB's DCB/HPL 245kV circuit breaker with a power frequency capable of withstanding a voltage of 460kV and the use of controlled switching Switchsync F236.

Voltage variation effect

When evaluating the two possible compensation system concepts, the impact of the voltage variation at the high voltage, as well as the smelter medium voltage, need to be considered. The tertiary filters (MV) have a lower but similar effect on the primary voltage rise, as the tap changers within the regulation transformers are normally installed on the secondary

Figure 8: Voltage (top) and phase currents during energising of a 220kV compensation system

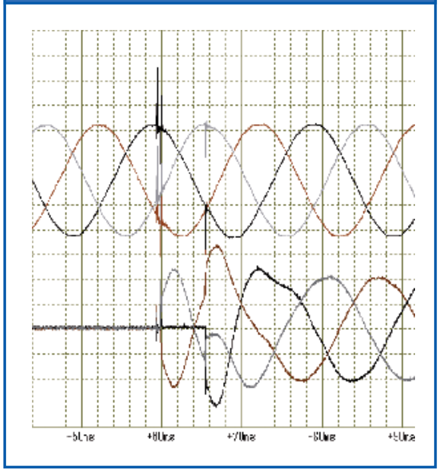


Figure 10: Primary voltage (blue) and plant voltage 33kV (red) variation when disconnecting or connecting a HV compensation systems

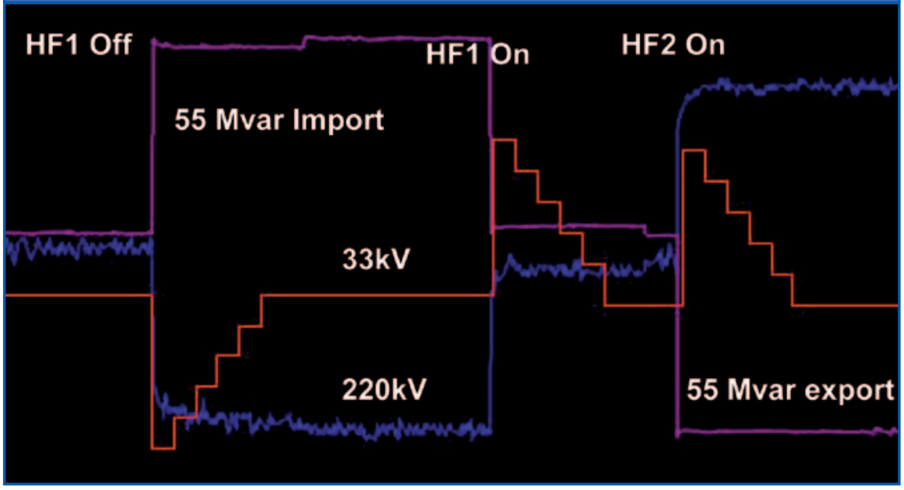
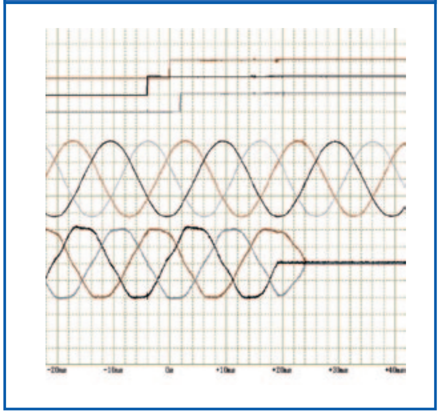


Figure 9: De-energising of a 220kV compensation system



winding for simplicity reasons. However, as there is impedance between the tertiary winding feeding the compensation banks, the voltage variation impact is not linear to compensation systems installed directly to the primary grid system.

It can be said that compensation systems connected directly to the feeding grid have a larger impact on the voltage variation. Figure 10 shows the impact on the grid voltage when connecting branches of 55Mvar directly to the feeding grid. Also shown is the impact on the medium voltage during the connection of the branches. This figure also illustrates the Mvar and grid voltage variation when a HV filter is connected to the feeding grid. In this case the feeding grid was 220kV.

Per smelter pot line compensation

The listing below shows the compensation systems installed during the last 15 years on green field and brown field projects (per pot line) but not retrofit plants. The list intends to illustrate the comparison in numbers but should not be taken as representative of all global projects.

- No compensation 4
- MV compensation 21
- HV compensation 5

Compensation systems connected to the power grid require detailed studies and a high number of parameters need to be known or made available by the power utility. When installed and operated on the grid the power utility will normally ask to control them as they are connected to their grid. Their drawback is that should the feeding grid become polluted by other consumers during the years to come, they will be loaded with this power quality pollution.

Compensation systems connected to tertiary windings of the regulation transformer are decoupled from the grids and are less affected by power quality pollution coming from the grid or which already exist in the grid.

Both compensation concepts eliminate the need for additional power generation units which would cost many times the initial cost of a compensation system, or additional cost for electrical power due to electrical losses created by poor power quality. ■

For more information, contact:

Max Wiestner,
Industry Manager Primary
Aluminium, ABB Switzerland,
max.wiestner@ch.abb.com

Christian Winter, Chief System
Engineer Rectiformers,
ABB Switzerland,
christian.winter@ch.abb.com

Reto Schraner, Chief Commissioning
Engineer, Sohar Aluminium Project
ABB Switzerland,
reto.schraner@ch.abb.com

Contact us

ABB Switzerland Ltd
Segelhofstrasse 9P
CH-5405 Baden 5 Dättwil
Phone: +41 (0)58 586 84 44
Fax: +41 (0)58 586 73 33
E-Mail: process.industries@ch.abb.com

www.abb.com/aluminium

Power and productivity
for a better world™