Low cost ferroalloy extraction in DC-arc furnace at Middleburg Ferrochrome

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Transaction Paper

Synopsis

Middleburg Ferrochrome (MFC), a company in Samancor Chrome, commissioned a new ferrochrome smelter in March 2009. This is a 60 MW DC-arc furnace with a DC power supply for the smelting of Transvaal chromite ore fines.

With the benefit of 12 years' experience with this technology while operating a 44 MW DC-arc furnace, MFC mitigated all known challenges and considered up-scaling risk in the new plant, which had a rapid ramp-up to full power in Q2 of 2009.

Good operating practices, as made possible by robust equipment selection, including a thyristor rectifier set of proven technology, and operation with optimal slag chemistry, leads to a safe and effective plant operation.

With the optimized furnace design and a correctly sized power conditioning system, using only standard (static) harmonic filters and a correctly sized smoothing reactor, the arc furnace is not a 'dirty load' for the utility, staying well within IEC limits for power quality.

A patented arc compensation system is installed and allows for full arc position control (to compensate for magnetic field induced arc deflection) so that a symmetrical crucible is maintained, significantly benefiting refractory life.

The principal benefits gained from the MFC process is the fact that ore fines are processed, without metallurgical coke, and higher chrome recoveries are achieved compared to other smelting technologies when using a DC open arc for smelting.

Keywords

Samancor Chrome, Middelburg Ferrochrome, ABB, smelting, DC arc furnace, arc compensation, power factor correction, anode, harmonics, thyristor, reactor, maintenance, refractory, ores, reductants.

Introduction

The most commonly and traditionally used technology for ferroalloy smelting is the submerged arc furnace. However, for some specific applications and electrical grid conditions, the DC-arc furnace, operating in open arc proves to be more cost efficient. MFC has waste experience in operating both types of furnaces. Since a couple of years, MFC is convinced that for them the DC-arc furnace is the more economical option. The specific advantages for MFC, smelting ferrochrome fines in the DC-arc furnace and some of the furnace's characteristics are discussed in this paper.

The process principle of ferroalloy recovery

Ferrochrome production by DC-arc furnace comprises the following plant or processes:

- Raw material receiving and storage
- Ore drying
- Batch preparation
- Furnace feeding on a feed/power proportion basis
- Smelting
- Alloy and slag tapping
- Off-gas cleaning and furnace pressure control
- Effluent treatment
- Cooling water plant
- Various utilities for all the above.

The objective in raw material selection is to achieve the lowest input cost blend while achieving the quality targets contracted to the customer.

Typical ores in the production of ferrochrome are ore concentrates, screened fines out of other ore streams, low value ore fractions, and blended sweepings. UG2 ore as available from dedicated sources or as platinum mining operations can also be used.

Reductants are typically metallurgical coal and anthracite. Other carbon sources are also utilized as they are available. Slag conditioning is done with limestone and quartzite stone. All the raw materials are in the size fractions of less than 40 mm with no limit on the smallest fraction.

After smelting, the alloy and slag are tapped separately. Clean alloy tapping is done at approximately 1 570 degrees Celsius into same grade alloy fines, after which it is broken, crushed and stockpiled into bunkers for shipping in bulk.

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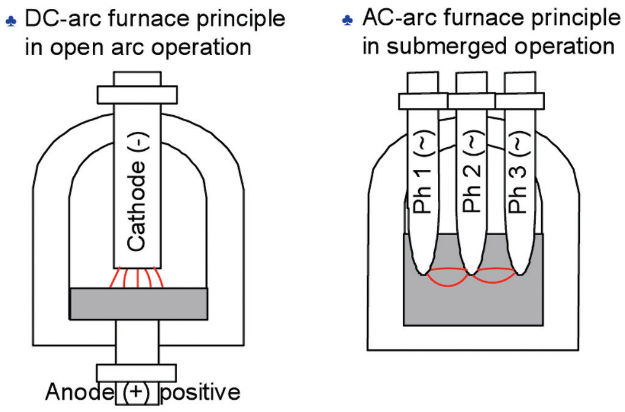

Figure 1—Principal schematic of two different furnace types used for ferroalloy smelting

Clean slag is tapped at approximately 1 650 degrees Celsius and removed by slag pots to a slag dump. The solid effluent filtered from the scrubber water does not contain hexavalent chrome, and is dumped.

Products from the process are ferroalloys of typically 53% chrome, 8% carbon, 0.5% silicon, 0.01% to 0.02% sulphur and 0.017% phosphor.

Description of electrical system in place

MFC's furnace M4 is designed to operate at 60 MW continuously. The nature of the process is such that you want to design the furnace to run at different arc impedance values because of variable properties in the feeding material and conditions. A low impedance results in lower voltage but higher current, and a high impedance require higher voltage but lower current. Since this power comes out of the same source (transformer), it must be designed such that it can fulfil both conditions. The more your electrical system is allowed to vary the impedance (while keeping power constant), the more flexibility you have to adjust to changing feeding material properties or even to operate with the electrode in submerged condition. In simple terms, the losses and costs for the electrical system are defined by the maximum current: higher current requires more copper in the transformer secondary winding, more thyristors in parallel at the rectifier and larger cross-section of DC busbar and cables from the DC busbar to the furnace electrode arm and finally also a bigger size of electrode. So it is more beneficial to design an electrical system that takes full advantage of the open arc condition: the open arc results in much higher impedance in the system than you would see in submerged conditions. This allows for the design of an electrical system, from transformer secondary down to the electrode, for lower current and higher voltage as you would use in submerged operation. This results in lower losses in the transformer secondary winding, in the rectifier and all DC current conductors as well as capital savings on equipment.

However, some flexibility in arc impedance (to cater for variable properties in the feeding material and conditions) is process-wise still required. MFC choose to design the system such that it can operate from 8 ... 12 mOhm at full power. This results in a transformer design of 102 MVA for the required 60 MW furnace power. Built into one tank, there are actually two independent transformers ensuring that the 33 kV grid sees a 12-pulse load current from the rectifiers. A 7 positions no-load tap changer allows adjusting the transformer secondary voltage such that an optimal power factor can be achieved on the MV level throughout the full operating range.

One vacuum breaker in the 33 kV substation feeds the furnace transformer. In the transformer vault, a motor operated isolator/ground switch is installed to provide a local and visible disconnection of the MV supply as well as an earthing, should one need to perform maintenance on the furnace transformer.

The two thyristor rectifiers are designed to operate each one at 45 kA DC current and at 850 V DC voltage. Rectifier and transformer need to include provisions in the design to operate at poor power factor (higher harmonic currents) and to handle drastic load swings that may come from disturbances in the furnace. An overvoltage protection at the rectifier and the transformer must take care of switching transients that come from the vacuum breaker and of the harmonic currents from the rectifiers that get amplified in the 150 m long cable from the 33 kV substation to the transformer vault. The thyristor's voltage safety factor, the factor between maximum operation voltage and maximum thyristor blocking voltage is > 2.5 to withstand possible exposure to high voltage.

After the rectifier, an aluminum hollow profile water cooled busbar system, is used to transmit the DC power to the electrode arm.

The most important device between the rectifier and the electrode arm is the DC reactor: made of a water cooled aluminum hollow profile, with a calculated number of turns (in air), it provides the arc with predefined impedance to keep the arc more stable.

In the MV yard, a harmonic filter of 40 Mvar is installed, to filter out harmonic current coming from the rectifiers and to compensate for the reactive power required for the rectifier's control reserve: the furnace has been designed to operate at approximately pf = 0.75, which is a bit higher than for an AC arc furnace. At this power factor, there is still enough voltage reserve to compensate for sudden changing conditions in the furnace without losing the arc. In practice, after some operation experience, the power factor is still better.

Designing the electrical system according the process's need

One of the most important tools to design an arc furnace system is the circle diagram of the furnace. The circle diagram shows the electrical characteristic of the furnace. With the circle diagram as a base, electrical engineers and process engineers estimate the optimal operating point which then allows a precise dimensioning of the electrical system. The red circle shows a typical operating range for a fixed tap voltage.

The power factor (cos ϕ) results from the firing angle on the thyristors: a theoretical firing angle of 0° would be equal to using a diode rectifier; the larger the firing angle, the later the thyristor starts conducting current and hence the lower the current and voltage output of the rectifier.

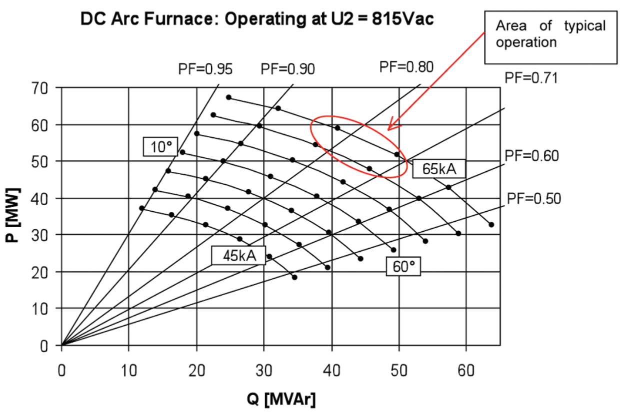

Figure 2—Sweeping on the curve of constant current (45 … 65 kA) at fix transformer secondary voltage: resulting P [MW], Q [MVAr] and power factor (cos ϕ) can be taken out of the diagram

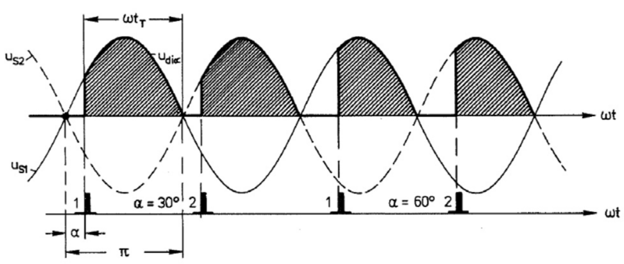

Figure 3—The bigger the firing angle α, the lower the rectifier's voltage and DC current. Also, the higher the firing angle, the higher the phase shift between voltage and current on the AC side, resulting in higher reactive power and hence a lower power factor cos ϕ (= active power [P] divided by apparent power [S])

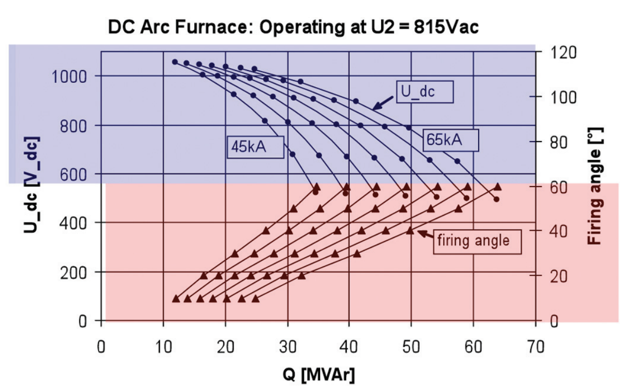

Figure 4—Lower part (red): moving along the curve of constant current (45 … 60 kA) with fix transformer secondary voltage: resulting firing angle and Q [MVAr] can be taken out of the diagram. Upper part (blue): moving along the curve of constant current (45 … 65 kA) with fix transformer secondary voltage: resulting U_dc [V] and Q [MVAr] can be taken out of the diagram

Keeping the arc under control

A rectifier local control panel (RLCP) takes care of control, protection and metering for the whole electrical system, except for filter protection, which is accommodated in a separate panel in the MV yard, close to the filter. The electrode control is implemented in the RLCP which is the closest control location to the thyristor control and current and voltage metering signals. Current control runs on a very high speed digital controller with a direct link to the voltage controller, which runs in a slower task of the same control system. The length of the arc is proportional to the voltage so that the voltage controller's output controls the position of the electrode through the solenoid valve in the hydraulic system of the electrode arm's mast.

For the furnace operator's comfort, all control parameters as well as status signals, actual values of voltage, current or temperatures are available at the operator's desk, some 150 m away from the RLCP. In practical terms, what matters to the operator of the electrical system are two preset values: power input and arc impedance (arc length). These two input values are sent to the RLCP, where they get 'translated' into DC current and voltage setpoints.

Advantage of the DC-arc for ferroalloy recovery

The DC-arc process allows the direct use of chromite fines (< 6 mm, 90% < 1 mm) without the need for expensive agglomeration techniques (pelletizing). Furthermore, non-coking coal can be used as reduction agent, which is cheaper than using metallurgical coke. Note that in a DC-arc smelter the power input is, theoretically, independent of the composition of the burden as the resistance is manipulated by the arc length as described earlier. This furnace technology is therefore regarded as one of the lowest-cost options for the production of ferrochromium.

Compared with AC-technology, it is much easier to bring the non-agglomerated fines into the bath. In an AC-arc furnace, the majority of fines would get wasted through the furnace off-gas system. The main advantage of the DC furnace is the jet effect in the bath and the concentrated heat zone around the single arc. Although in the beginning hollow electrodes were used, operation has proved that close feeding around the arc will have the same result, thus saving on costs by using standard graphite electrodes.

The process taking place inside the arc furnace is a reduction process: by using coal (C), the chromite fines, which are a metal oxide, frees its oxygen to form CO gases and liquid ferrochromium. Hereby the electrode serves as an additional C provider, reducing the total amount of coal added. The scrubbed off-gases, mostly CO, but relatively high in hydrogen content could be used e.g. in a steam power generation plant as already practised on several furnaces.

The latest researches by Mintek in South Africa on the behaviour of the open arc revealed that the arc actually does not add much to the total heat radiation (compared to submerged operation), to which the furnace sidewalls and roof are exposed. A much bigger share in that is the bath's surface, which is of the same size in submerged as in open arc operation.

In large power applications, respectively high current application, the AC technology reaches the current-carrying capacity limits of graphite electrodes earlier than the DC technology due to the skin effect. (The skin effect applies to the electrode as well as to the copper conductors in the high current system.)

The furnace's conductive bottom

The most critical part in a DC-arc furnace is the bottom electrode. Besides carrying the full current it has to withstand the metallurgical impact, caused by the different processes, with up to 1 700°C bath temperature. Whereas for the steel melting process the pin type electrode has been proven as adequate technology, the conductive bottom electrode has turned out to be the ultimate technology for the smelting process.

Since the smelting process is a nearly continuous process requiring very expensive refractory, a long lifetime (5–10 years) is the most important requirement for the bottom electrode. In addition, it has to withstand metallurgical erosion occurring from time to time on the bottom of the furnace. The conductive bottom electrode consists of a copper plated steel plate covered by metalized bricks. This ensures conductivity even if local spots are covered by non-conductive material and by using bricks to withstand the metallurgical impact. Another advantage of using bricks is that the metal part of the bottom electrode requires only air cooling. Compared to other water cooled system, this presents an important safety advantage.

It can be said that with today's conductive bottom, this type of electrode provides a number of advantages to the process and furnace operation and it is no longer the 'headache' of the DC technology as many people regarded it when comparing it with AC technology.

The merits of the DC-arc

Ideal for the bath to mix with the fines from the feeding is the mechanical mixing and stirring effect caused by the DC plasma arc: the arc in a DC furnace is a sustained high-velocity high-temperature jet, driven by electromagnetic acceleration (the Maecker effect) in the constricted region near the arc's root on the electrode surface. At industrial current levels, the velocities in the arc can reach many kilometers per second, and this imparts a significant thrust force to the surface of the molten slag or metal bath beneath. Interaction between the arc jet and the molten bath results in a great deal of turbulent splashing and mixing, stirring the bath and homogenizing its properties to a large degree[1].

The thyristor technology allows for a fast power and resistance control to the arc furnace: Normally, you want to keep the power at the maximum, which is 60 MW in the case of MFC, but you still need to adjust the arc length from time to time in order to respond to changing bath chemistry: the operator may i.e. reduce the resistance setpoint from 12 mOhm down to 11 mOhm. The high speed control system of the rectifier receives the new setpoint, calculates the new DC voltage (proportional to the arc length) and DC current setpoint and adjusts DC current within milliseconds and the new arc length within a couple of hundred milliseconds by activating the proportional valve of the electrode's mast.

With rising costs for electricity, it is interesting to look at the total electrical energy used. NUCOR Steel (USA), for example, experienced that a DC furnace uses 8% less electric energy than a comparable AC arc furnace (and with the same chemical energy input). Whether a similar figure is applicable when comparing a conventional AC submerged arc furnace with a DC-arc furnace operating in open arc mode needs to be investigated. Operating with higher resistance and thereby using lower current and higher voltage, transformation and conductor losses should be less and the fact that less energy is required for smelting fines than pellets, lets expect one significant savings as well.

From a metal recovery point of view, MFC experienced with a typical AC submerged arc furnace 78–84% chrome recovery, whereas the DC-arc furnace results in approximately 90% chrome recovery with the same raw material.

Optimized furnace design

The design of the 60 MW smelter at MFC was undertaken by an EPCM contractor, GLPS Project Management and Engineering Services in Middleburg, and the Samancor Chrome team. The general design philosophy taken was to build a plant which would have the following attributes:

- Safe operation of plant
- Stand-alone infrastructure where ever possible
- Maximum automation
- Robust in both the core furnace and peripheral equipment.
- Maximized local supply of the equipment.

The operation of the 60 MW smelter can be considered intense and steps were taken to ensure that plant operators are unconstrained by operational issues, including raw materials preparation, batching, feeding, tapping, gas cleaning, effluent treatment and water management. The necessity of accurate power to feed control for DC-arc furnaces is achieved by using the actual DC power as an output from the high power rectifier controller as an input into the plant control PLC. From this input and a required feed-rate setpoint, as specified by the process engineer, a feed kg/s output is sent to a loss in weight system.

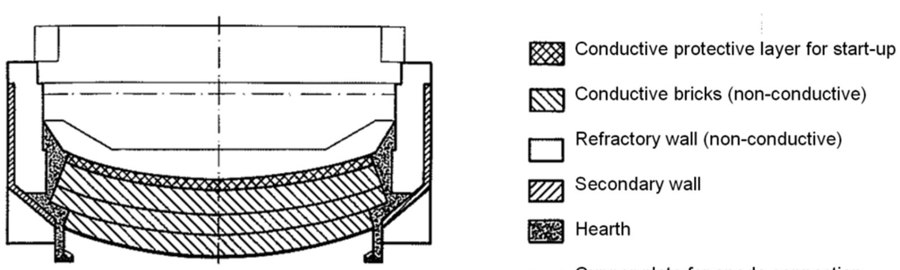

Figure 5—Sketch of conductive bottom electrode[2]

Accordingly, the operator can focus on the process, with the objective of stripping the slag to a very low residual chrome oxide level.

Note that once the melt has no remaining reducible components, the process will rapidly move into a superheated slag. This is not the desired operating mode, but the designer needs to make allowance for this possibility in the overall plant design. Similar conditions can be found in the event of insufficient reductant being available in the process.

The design team, using the experience gained in the operation of the existing 44 MW smelter, increase the shell diameter by 1 m. This was under the consideration of both liquid inventory and gas handling in the furnace. Optimal thermal efficiency, as expected from the smallest possible vessel area, was balanced against the considerations of internal gas velocity, raw material carry-over, insulation distances and future maximum power inputs. Note the refractory life of a DC ferrochrome smelter is measured in years, accordingly the tonnage of refractory used is a capital item, not an operating cost as in most melting plants.

Compared to the 44 MW smelter, the conductive hearth power density increased by 50% and the total hearth power density increased by 24%. Freeboard power density increased by a similar amount. These were the upscaling numbers which indicated that this larger plant would have a higher theoretical efficiency than the baseline plant.

At increased DC voltage, the risks associated with stray arcing increase. It was known that arc power versus bath power is in the ratio of approximately 15:1, so reduction of DC voltage is not an option. Accordingly, measures need to be taken to monitor and respond in the event of DC potential building up in undesired areas, including the roof support system, the roof sections or the gas off-take.

Nevertheless, in the event of a stray arc, the water loss into the furnace must be restricted to the lowest possible amount. System Spray Cooled Equipment, as supplied by Sparcmelt, the local licencee, provided spray cooled centre roof, roof panel and duct systems. Desirable attributes of the spray cooled equipment are low water loss in the event of arc damage, good heat transfer capacity even at elevated rates, and good formability for the duct configuration required on this plant. Experience to date has been positive in these regards.

For critical areas where pressure cooling is unavoidable, automated pressure testing of water circuits is installed as it is the MFC standard.

A section view through the furnace would show substantial differences to a traditional AC furnace. It is our observation that a DC smelter is not an AC smelter with a single electrode in the middle. Consequently, the low roof angle and large freeboard of the furnace require upper side wall refractory cooling elements to extract heat at up to 50 kW per square metre. For this technology, Hatch Furnace Division were contracted to provide the designs and the plate cooler elements. This is a duplication of a system that was in successful use for 6 years on the 44 MW plant.

The configuration of the plant was tailored to the needs of ferrochrome smelting, where safe operation, high operating rates, good chrome recovery and production of the best possible grades are required.

Refractory lifetime and general maintenance

The operation and maintenance of a smelter require sustained high power inputs to be maintained on a continuous basis. Ferroalloy production from furnaces is not a batch system, but continuous with power on tapping. Maintenance is aligned to this operating practice.

For refractory maintenance, the furnace lining is insulated from liquid contact by the frozen bank formations at the base of the sidewalls.

The liquid contact occurs in the taphole area. Maintenance of the taphole is a combination of time based and condition based concepts. As mentioned previously, the taphole design is not suitable for alloy or slag in a superheated condition. Accordingly, in an event when very well stripped slags or very fluid alloy has been encountered, a taphole will need maintenance.

Deep taphole maintenance is typically done on an annual basis by breaking out the frozen metal heel and inserting new refractory material to the original depth.

Catastrophic events that would cause a lining failure are loss of control on the feed to power proportioning, or water ingress behind the lining or into the hearth. The lining of the DC-arc smelter for ferrochrome is magnesite, pitch impregnated at installation but vulnerable to hydration when hot. The design of all cooling elements and systems is aligned to minimizing water loss into the furnace in the event of a failure, and disciplined accounting for water lost from the total system. The principle of cooling water management is for loss of water alarm to be triggered at values of less than 0.5 cubic metres, for the necessary fault finding to be done. This of course demands fully sealed systems, including the spray cooled equipment.

Good lining management includes the aspect of arc deflection control. High current DC-arc furnaces experience a force on the open arc that is large enough to need mitigation. Failure to address this aspect of the process leads to an asymmetry in the furnace bath and to such an extent that the lining failure in the metal/slag zone or the freeboard can occur.

The 60 MW DC-arc at MFC has a separate power supply installed to provide counteracting forces, at the arc zone. The system is designed and patented by GLPS to provide active control of the degree of arc compensation in conjunction with the high power rectifier. This system is currently in operation.

Furnace power supply maintenance requirements are very low, and are limited to ensuring that software backup is maintained, the heat exchanger for the power supply cooling water is operating to specification and the harmonic filters/power factor correction equipment is clean and correct.

Pure demineralized water is the cooling medium at Middelburg as the worst winter conditions do not make glycol addition necessary. Maintaining the conductivity of this water is necessary to prevent corrosion of the power supply parts.

The power electronics and controller components as supplied by ABB High Power Rectifiers have proven to have exceptional reliability at MFC, with no thyristor failures having been experienced in 12 years of operation at the 44

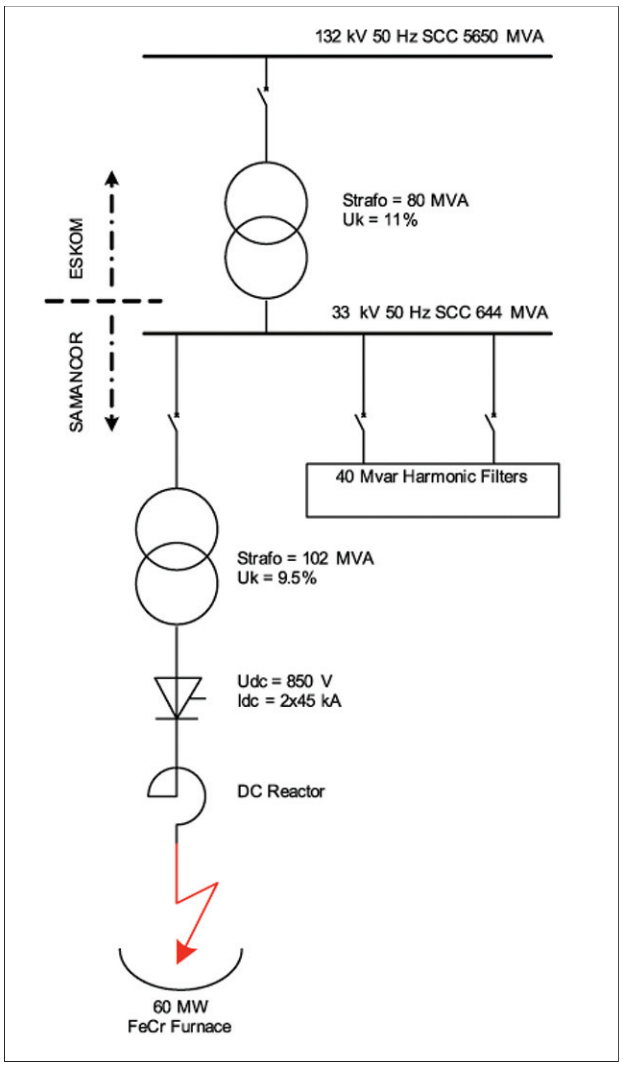

Figure 6—Single line diagram of power system from Eskom's PCC down to the DC-arc furnace

MW plant. Similarly, the rectifier transformer has shown excellent reliability in operation. MFC has similar expectation for the new plant.

Power quality considerations

System overview

The M4 Furnace is feed from a 132 kV / 33 kV Eskom substation close to the smelter, with is also MFC's PCC (point of common coupling) towards EskomM. During the tendering phase, engineering could clearly see that no static var compensation (SVC) was needed for this type of installation. As the network's short circuit capacity is very high a reasonable sized DC reactor would be sufficient to fulfill the IEC flicker standards. In regard to the open arc operation, the DC reactor also needs to be designed for a stable arc operation. Due to the fact that the FeCr process is continuous, the changes in reactive power demand are also moderate compared to a scrap furnace and therefore the requirement for an SVC to maintain the power factor at 0.99 was also not given.

To reduce harmonics to and improve the power factor a 40 MVar harmonic filter system is installed on the 33 kV bus and the energizing of the filters is done by the rectifier control system to adapt to the actual demand. Additionally a 7-position tap changer on the rectifier transformer was foreseen to ensure an optimal power factor within the whole range of arc impedance for which the system is designed.

What is Flicker?

Flicker is a non-periodical voltage fluctuation visible to the human eye. It is defined and quantified through the frequency response to sinusoidal voltage fluctuations of a coiled filament gas-filled lamp (60 W–230/120 V) combined with the human visual system. The response function is based on the perceptibility threshold found at each frequency by 50% of the persons tested, which results in a weighting curve with 8.8 Hz to be most dominant.

The units of the flicker are the following:

P_{st_95} (perturbation short-term) Interference factor during 10 min with 95% of the measured samples staying within the limit

P_{lt_98} (perturbation long-term) Interference factor during 2 hours with 98% of the measured samples staying within the limit.

Flicker is normally measured at the PCC (point of common coupling) on high voltage. A typical limit requested by utility is Pst_95 = 1.0

Flicker calculation and measurements

With a flicker simulation tool which has been developed and proven over many years and with various types of DC arc furnace applications it could be calculated that there was no need for an SVC to reduce flicker on this project. Main reasons are:

- ➤ The short circuit capacity of the supplying network is high enough
- ➤ Providing a well proven adaptive arc control logic to operate current and voltage control always at optimum parameters in the rectifier control system even if feed conditions change

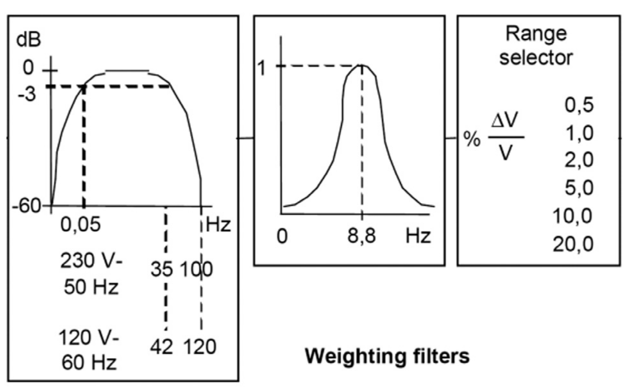

Figure 7—The norm DIN EN 61000-4-15 specifies how to measure flicker

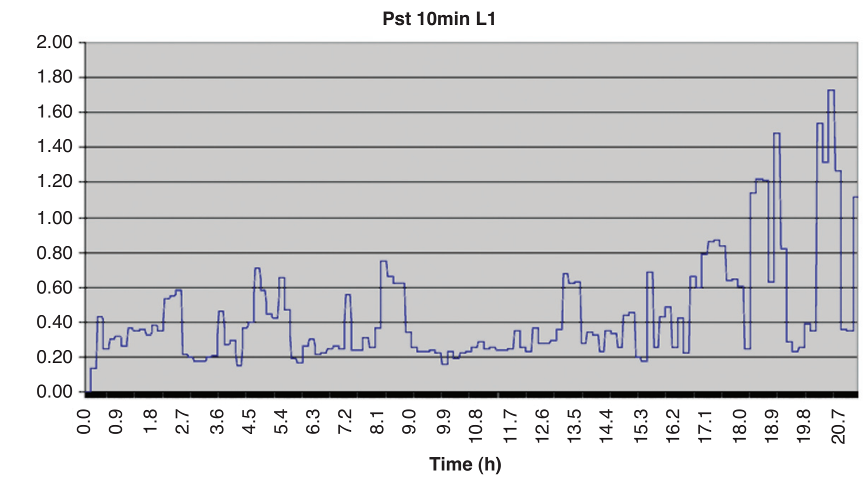

Figure 8—Actual flicker measurements taken on the 33 kV bus with the furnace running at full load (60 MW)

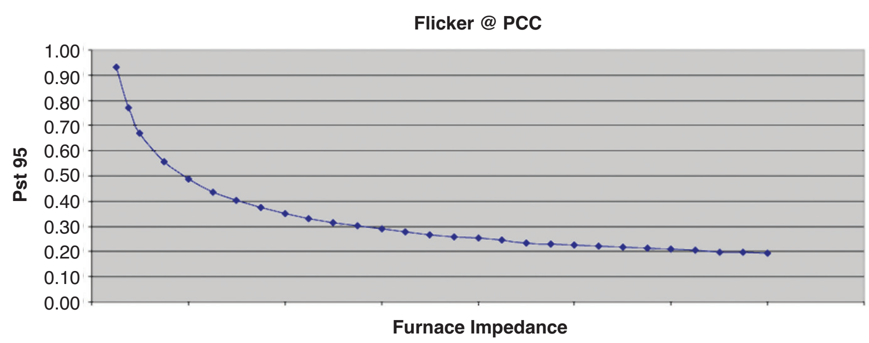

Figure 9—The influence of the reactor sizing on the flicker level. The bigger the reactor's impedance, the lower the flicker. What can also be seen is that this effect saturates from a certain point onwards. When entering the saturation area, because of the higher losses, the weight and the cost of the DC reactor, it is not economically viable anymore to further increase the reactor size. Should a further flicker level reduction still be required, an SVC needs to be installed. In MFC's case, the reactor size is far away from this saturation area

- ➤ The FeCr smelting process which is continuous and therefore no bore in and no frequent transformer switching takes place
- ➤ A correctly sized DC reactor
- ➤ Allowing enough control reserve for the current controller. Typically a firing angle at the operating point of 32° is recommended (refer to circle diagram in Figure 2).

Taking all this into account, the calculation determined a Pst_95% of 0.35 at the PCC which is far below the limits requested by the electrical power authorities, who do not allow one to exceed a Pst_95% value of 1.0.

The calculated Pst_95% value for the 33 kV level is 2.4 which was verified by above measurement on site after putting the furnace into service, running at 60 MW.

Not using an SVC offers MFC two major advantages: the saving of equipment cost and lower operating losses keep the overall costs low.

Harmonics

Although no SVC is installed, the harmonic level injected to EskomM is not allowed to be higher than the local standards. As the rectifier system generates a significant amount of harmonics in various frequencies (typically 5th, 7th, 11th, 13th, etc.) a 40 MVar harmonic filter system split into 3 branches is installed. To cater for the very dynamic changes in load of an arc furnace it is very important to damp the filter circuits and therefore eliminate the possibility of resonances which would lead to destruction of the capacitors in the filter circuits. Compared with other applications arc furnaces call for a very robust design of the filter circuits to ensure a reliable operation of the plant.

Power factor

As the FeCr smelting process can be considered continuous it was sufficient to implement the harmonic filters and a tap changer on the rectifier transformer. In the case of variable properties in the feeding material and feeding conditions, the tap changer is required to ensure that the power factor can be held within the limits. The design firing angle of 32° defined the size of the transformer and of the harmonic filters to achieve a power factor of 0.99 at the PCC. Here again the circle diagram in Figure 1 was the basis for the decision. Operating profile and design firing angle of 32° define the

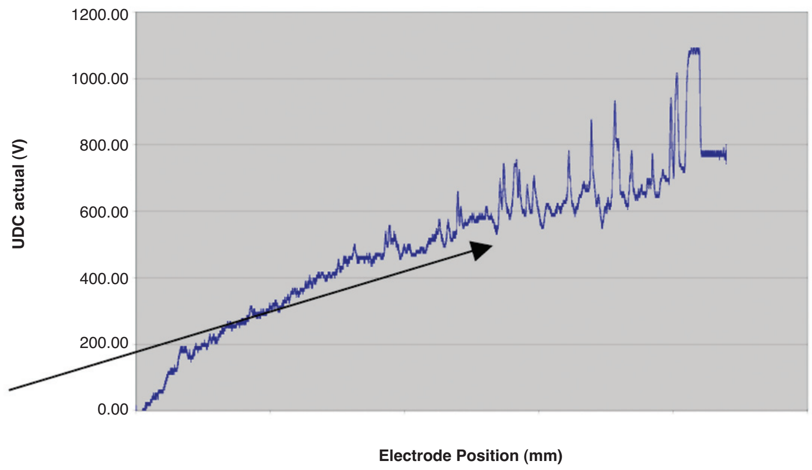

Figure 10—The arc voltage in relation to the arc length at a constant current and fixed DC reactor impedance. It can clearly be seen that from a certain point onwards the voltage gets more and more instable and finally the arc extinguishes completely

rectifier transformer size, as well as the requested reactive power in the harmonic filters to reach the power factor targets set by the electrical power authorities of 0.99 at the PCC.

DC reactor size

The two main goals of a DC reactor are:

- Flicker mitigation
- Production increase due to higher energy density and increased arc stability even at longer arcs

Flicker mitigation

The size of the DC reactor is in a direct relation with the magnitude of the flicker that is generated by the flashing on the open arc. Depending on the characteristic of the arc furnace, the ratio of network short circuit capacity to the furnace transformer's apparent power, a corresponding DC reactor impedance has to be chosen to fulfil the flicker level requirements given by the local electrical power authorities.

Production increase

For the ferrochrome smelting, special attention has to be given to the operation of the furnace with a long, free burning arc which adds an extra degree of arc instability. When increasing the reactor size, the time constant of the high current system is increased. Higher time constant combined with an optimal current and voltage control system results in a more constant power input to the furnace. This increases the energy into to furnace and therefore speeds up the melting process without increasing the power setpoint. No additional losses are generated and the electrode consumption is also reduced.

The arc stability is also related to the DC reactor size. To ensure a stable and non extinguishing arc, a reactor size has to be chosen depending on the operating point of current and voltage, which can be take from Figure 2. By eliminating arc extinguishing, the production is increased as the power is never interrupted and the arc does not have to be restriked, which not only causes unwanted network disturbances but is also time consuming and therefore reduces the output of the furnace.

By choosing the optimal reactor size, the instability point of the arc can be moved to higher voltages, therefore allowing a stable operation even at longer, free burning arcs. An optimal sized reactor reduces flicker, increases production, reduces radiation losses and electrode consumption, and is therefore very economical.

Conclusions

A consequent employment of various new merits from innovation, development and long time operational experience of a ferroalloy producer, MFC, together with a number of involved equipment and technology suppliers led to an outstanding performance of MFC's M4 DC-arc furnace in terms of productivity and economic viability.

For MFC and their EPCM, GLPS, the DC-arc technology is today the first choice for ferrochrome smelting, satisfying demanding requirements on production, maintenance, and power quality.

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