SVC brings productivity improvements to OneSteel

A Static Var Compensator commissioned in the meltshop at OneSteel Laverton provides voltage support to the EAF. Benefits include more power to the EAF, which means tap-to-tap time is reduced, as well as lower energy and electrode consumption and limited flicker and harmonics to the supply grid.

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The SVC at OneSteel has improved productivity and reduced flicker on the supply grid

Stage	Measure	Active power at EAF (MW)
1	Tycap	49
2	SVC	58.2
3	Electrode regulation adjustment	58.7
4	Tap down one notch	55.5
5	SVC with voltage control	56.6

Table 1 Improvement of active power into the EAF

A Static Var Compensator (SVC) has been commissioned in the melt shop of OneSteel at Laverton North, Victoria, Australia. The SVC, supplied by ABB, replaces an ASEA Tycap SVC, installed in 1980. This was outdated and larger facilities were needed in its place. The new SVC provides better voltage support to the electric arc furnace (EAF), especially during the initial melt down period and reduces flicker and harmonics in the local supply grid, created by the operation of the EAF, to acceptable levels.

The melt shop comprises an EAF rated at 77MVA and a ladle furnace rated at 11MVA. In both cases, the power factor (PF) = 0.8.

The power supply to the melt shop comes from the 220kV public grid through a dedicated 220/66kV substation. From the substation, a 7km, 66kV overhead line goes to the steel plant. The incoming short circuit capacity at the steel plant is less than 600MVA, a very low value in relation to the ratings of the furnaces and, unless properly remedied, leads to voltage fluctuations and other network disturbances during furnace operation. The point of common coupling (PCC) used to be at 66kV, but due to the low short circuit capacity it was changed to 220kV.

The replacement SVC is larger and has higher dynamic response than the vintage Tycap, which means that melt time, as well as grid distortion caused by the furnace, is reduced.

The environmental demands on the SVC are severe. In the summer, the ambient temperature can exceed 40°C for days. Dust and fumes from production is corrosive and hard to remove.

In the melt shop, the 66kV feeder voltage is reduced to 22kV by two parallel 50MVA, 66/22 kV step-down transformers. A small series capacitor, located upstream from the transformers at 66kV and previously operated in tandem with the Tycap was dismantled upon the arrival of the replacement SVC.

Productivity improvements

An SVC not only mitigates random voltage fluctuations at the PCC, but also brings about an increase of the RMS value of the EAF bus voltage. This enables higher active power in the furnace, which can benefit the steel plant as follows[1], [2]:

- Shorter melting times;
- Reduced specific electrode consumption;
- Reduced specific energy losses; and
- Reduced wear of furnace lining.

Furthermore, an improvement of the power factor at the PCC enables a reduction of plant losses emanating from the flow of reactive power, and opens up more favourable power rates from the local power supply utility. These factors all offer potential for improving plant productivity and economy.

The increased RMS value of the bus voltage results in higher power into the EAF. This enables a decrease in tap-to-tap time for the furnace. With this, more steel can be melted per day. **Fig 1** summarises the advantages in terms of Arc power (P) and the voltage at arc furnace bus (U) plotted against furnace current.

Power increase in the EAF

The upgrading of dynamic compensation at the EAF bus has taken place in five stages since 2008 (**Table 1**).

The 9MW increase in furnace power from stage 1 to 2 was regarded as impractical to use at the time. To slightly reduce the increase, a one notch tap down was performed, reducing

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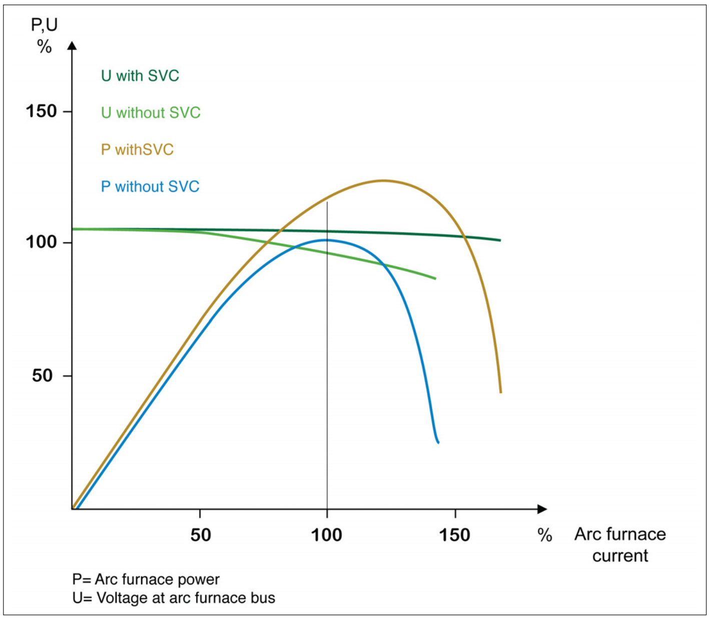

Fig 1 Impact of SVC on EAF operation Y axis = Arc power (P) & Voltage at arc furnace bus (U) (%) X axis = Furnace current (%)

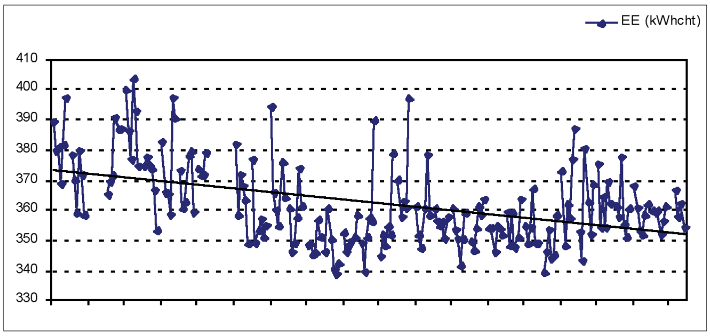

Fig 2 Electrical energy consumption trend per charge tonne (kWh)

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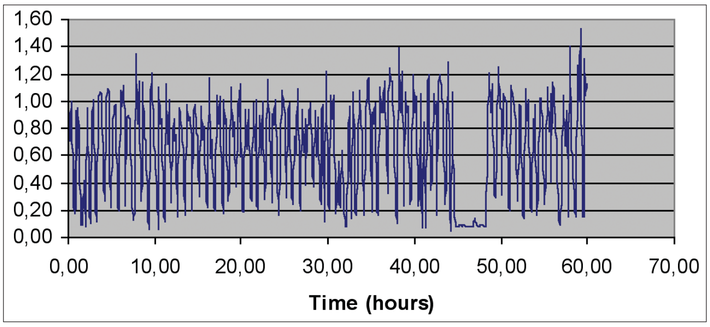

Fig 3a Flicker without the SVC

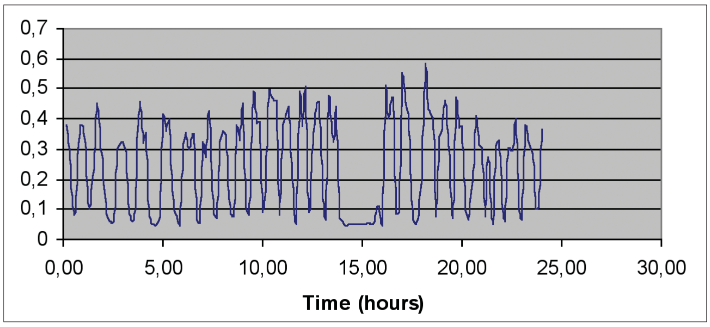

Fig 3b Residual flicker with the SVC in operation has been reduced by a factor of over 2

the EAF power by 3MW. Finally, a change from reactive power control to voltage control improved the 22kV bus voltage regulation to ±1.5% (~330V), which has increased the furnace power to 56.6MW. The power into the EAF has increased by 7.6MW to 56.6MW, equal to 15.5%.

Power on time

The power on time dictates the complete cycle time for the EAF (tap-to-tap time). With the SVC in operation, the power on time has dropped significantly, improving meltshop productivity from 39 minutes in stage 1 to 35 minutes in stage 5. This four minutes gain represents a reduction of power on time by 10.3%, opening up for additional charges per day.

Decreased power consumption

Fig 2 shows the progressive decrease of electrical energy consumption per tonne charged. The former 380-390kWh/cht has decreased to 350kWh/cht ie a decrease of 8-10%. An alternative way of expressing this is that the energy losses in the melting process have decreased by 8-10%.

There are two main reasons for this considerable decrease of energy losses:

- With the shorter tap-to-tap time, the radiation losses per melt go down.
- With the SVC, the overall power factor of the plant has increased to close to 1, against 0.8 at stage 1 of the meltshop upgrade. That means the flow of reactive power has diminished, and with it, the losses associated with the flow of reactive power.

Specific electrode savings

The graphite electrode consumption can be split into two constituents:

- Side oxidation, mainly dependent on tap-to-tap time;
- Tip consumption, mainly dependent on electrode current.

In this case, the electrode current remains the same but the tap-to-tap time is reduced. Thus, less side oxidation results, leading to reduced electrode consumption.

Specific refractory savings

Specific refractory wear is decreased due to the shorter time spent for each melt. The more efficient and stable arcing in the EAF due to the SVC and a series reactor also results in reduced refractory wear.

Table 2 summarises all the productivity improvements.

EAF power increase	15.5%
Power on time reduction per melt	10.3%
Energy consumption reduction per charge tonne	8-10%
Electrode consumption reduction per charge tonne	2.8%
Power factor improvement	From 0.8 to 0.97

Table 2 Summary of productivity improvement

Grid impact of an EAF

The melting process inside an EAF is erratic, sometimes resulting in an 'electrical short' within the furnace's electric circuit. It means the consumption of reactive power strongly fluctuates in a stochastic manner. The fluctuation of reactive power flowing through the circuit reactances results in voltage fluctuations, which are most clearly seen in the flickering light of incandescent lamps serviced by the common grid. Spectral analysis confirms that lamp flicker caused by EAF action is severe around frequencies for which the human eye is particularly sensitive, ie below 20 cycles. Flicker is a very annoying sensation and easily becomes a source of complaints to the grid company from neighbouring customers.

Flicker is expressed by means of the Flicker Severity Level P_{st} which directly expresses the degree of irritation. The most critical part of the voltage fluctuation spectrum falls around 8Hz, which is where the human eye is at its most sensitive to light fluctuations. The amount of flicker that arises as a consequence of EAF operation depends on the size of the EAF and the short circuit power of the grid at the PCC. With an EAF having a short circuit rating of S_{SCEAF} and a grid having a short circuit power of S_{SC}, a flicker expectation figure can be derived from the following equation[3].The constant Kst (severity factor) for cold start-up of an EAF is typically around 70.

$$P_{st} = K_{st} \frac{S_{SCEAF}}{S_{SC}}$$

The situation is aggravated by the appearance of inter-harmonics in the furnace current, interacting in a nonlinear way to produce additional flicker components.

In the given case, S_{SC} amounts to some 8.000MVA at the 220kV PCC. With S_{EAF} = 77 MVA, S_{SCEAF} can be estimated to some 140MVA. (The impact of the ladle furnace is insignificant in the context). Furthermore, with Kst set to 70, the Pst value (uncompensated) will be around 1.2. This agrees well with actual flicker measurements performed at the plant (**Fig 3a**). With the SVC in operation, flicker has been reduced by a factor >2 and is significantly below the required value of 0.8 (**Fig 3b**). By minimising the flow of reactive current through the PCC, voltage fluctuations and thus flicker is minimised.

Main circuit design

The SVC is rated at 22kV, 0-115Mvar capacitive. To achieve this operational range, a total filter power of 115Mvar was installed, divided into three separate filters. The SVC comprises the following main branches:

- A TCR (Thyristor Controlled Reactor) rated at 115 Mvar;
- A 2nd harmonic filter rated at 25 Mvar;
- A 3rd harmonic filter rated at 55 Mvar;
- A 4th harmonic filter rated at 35 Mvar.

A single-line diagram of the SVC and furnaces is shown in **Fig 4**.

By phase angle control of the TCR, the RMS value of the current through the reactor can be continuously controlled from zero up to the value given by the rated inductance of the reactor. Together with the capacitive reactance provided by the harmonic filters at 50Hz, the total dynamic range of the SVC is made capacitive. Thus, the overall dynamic range of the SVC installed at OneSteel is 0-115Mvar (capacitive). Harmonics generated by thyristor control of the reactor current are absorbed within the harmonic filters.

Thyristor Controlled Reactor

The thyristor valve consists of single-phase assemblies. The high power thyristors are electrically fired (ETT) and the energy for firing is taken from snubber capacitors in the valve. Thyristor firing orders are communicated via optical light guides from the valve control unit. This type of system is normally called indirect light firing.

The thyristor valve employs series connected 5" thyristors, water-cooled, together with associated snubber circuits, thyristor electronics, heat sinks and clamping arrangement. The valve is designed with free standing single assemblies, each with a stack of BCT (Bi-directionally Controlled Thyristors). In the BCT, anti-parallel thyristors have been integrated on a common silicon wafer so only one thyristor stack is required per phase. This means only half the number of thyristor housings and heat sinks are needed. The number of components in a valve and the number of connection points for the water-cooling are reduced. This is obviously an improvement from a manufacturing, maintenance and reliability point of view.

There are heat sinks at the top and bottom of each stack as well as between thyristors to remove thyristor heat loss, also serving as elec-

Performance parameters	Contractual values	Measured values
Power factor	≥ 0.95	0.97
Flicker, Pst (95%)	≤ 0.8	0.48
Total Voltage Distortion, THD (95%) (%)	≤ 1.5	0.86
Voltage fluctuations (95%) at 22kV (%)	≤ ±2	±1.5

Table 3 Performance values

trical connection between thyristors. It means the thyristors are cooled from both sides.

Air core reactors

In the TCR, air core, glass fibre insulated and epoxy resin impregnated reactors are used. This provides a self ventilated, low loss, environmentally sturdy design with linear inductive characteristics.

Harmonic filter design

By introducing damping in the 2nd harmonic filter, possible problems with inter-harmonics and parallel resonances can be mastered. The 2nd harmonic filter is designed as a C type filter, consisting of a reactor and capacitors connected in series to attain the required tuning. The capacitors are sub-divided into two parts in series, where a resistor is connected across the tuning reactor and the nearest capacitor part. The latter is chosen such that it forms a series resonance circuit with the reactor at the fundamental frequency. The fundamental current bypasses the resistor, avoiding resistive losses.

The 3rd and 4th harmonic filters are designed as band-pass filters and consist of a reactor and a capacitor in series to attain the required tuning.

Control system

The control system is based on the ABB Mach 2 concept, which is a system of both hardware and software developed for power applications. The concept is built around an industrial PC with add-in boards and I/O racks connected through standard type field busses such as CAN and TDM. The objective of the control system is to reduce flicker generated by the load and to improve the power factor in the bus feeder.

The input signals to the control system are generated in current and voltage transformers located in different locations in the plant. These are used by the control system for controlling, supervising and synchronising purposes. The control system processes the input signals, calculates the phase-angle for triggering of thyristors and converts them to control pulses for the TCR thyristor valve. These pulses are transmitted to the Valve Control Unit (VCU) and from the VCU to the valve via fibre optics.

The SVC can be controlled from the SVC control room where there is an operator workstation (OWS) based on a personal computer. As back-up to the OWS, there are two pushbuttons in the front of the control cubicle for SVC-ON/OFF control.

Control strategy

The aim of the SVC is to control the power factor on the incoming line, stabilise the voltage at the furnace bus and reduce the flicker at the PCC. The automatic control system consists of an open loop phase-wise susceptance regulator and a closed loop susceptance regulator. All regulators are located in the Mach 2 computer.

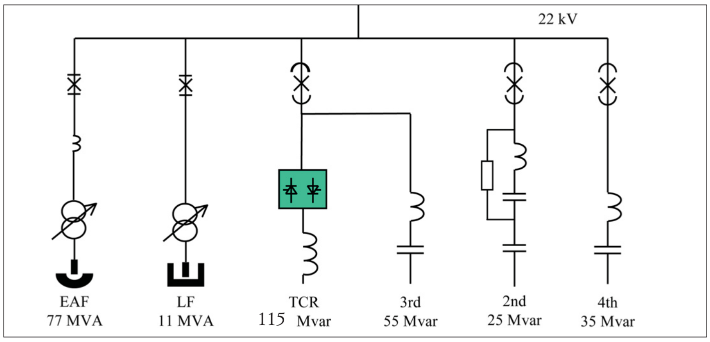

Fig 4 Single-line diagram, furnaces and SVC

Open loop control (Flicker regulator)

The main objective of the open loop regulator is to generate fast susceptance references for the SVC to suppress flicker and phase unbalances. The SVC compensates for the EAF currents consisting of the reactive part of the positive phase sequence current, and both the active and reactive part of the negative phase sequence current. Hence, the voltage drop over the AC network is minimised.

Closed loop control

In addition to the open loop control there is a closed loop control. Three different control strategies can be used:

- Reactive power control;
- Power factor control; and
- Voltage control.

Reactive power control: The purpose of this control is to keep the reactive power in the incoming feeder close to zero and thereby a power factor close to unity in the incoming EAF bus feeder.

Power factor control: The active and reactive network power are calculated and the actual power factor (PF) is derived. Based on the PF setting, the reference of the reactive power (Mvar) is set to correspond to the required PF.

Voltage control: The purpose of voltage control is to keep a desired voltage in the EAF bus feeder. With this control strategy, the output from the SVC can be either capacitive or inductive, depending on the voltage. (The power factor requirement cannot always be fulfilled with this strategy).

Performance

The contractual versus measured performance values shown in **Table 3** are valid at the 220kV PCC. As can be seen, the SVC more than fulfils the contractual requirements.

The Power Factor recorded in **Table 3** has not reached 1 as the SVC is run in voltage control mode. To keep the voltage stable, approximately 8Mvar from the SVC have been used to compensate for the voltage drop in the feeder from 220kV. As a consequence, it has not been possible to bring the power factor fully to one.

The SVC offers productivity improvement of the metallurgical process, as well as cost reductions. Power into the EAF is increased, which means the tap-to-tap time is reduced, as well as specific energy and electrode consumption. An improved power factor can enable a more favourable tariff from the power supplier.

As a device for power quality improvement, the SVC provides a decrease of voltage fluctuations, as well as harmonic reduction and reduction of phase imbalance, which would otherwise create nuisance for other power consumers connected to the same grid, especially flicker of lights which is an annoying sensation to people and also increased energy consumption by motors, both synchronous and induction. ■

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