A stable arc at higher voltage is the key to achieving increased production and reduced operating costs in a steel mill.

This can be achieved by using ABB’s ARCARE® system. The system provides better use of installed capacity, resulting in a highly efficient way to produce more steel. Moreover, installing the system causes minimum disruption to the ongoing production.

Based on Hatch SPLC (Smart Predictive Line Controller)™ technology, the ARCARE® system allows the alternating current electric arc furnace (AC EAF) to operate at higher power, with improved arc stability.

This reduces tap to tap time, electrical energy consumption, electrode consumption and electrode breakages by eliminating vibrations due to the absence of current swings. Reduction in power-on time and balanced currents across all phases lowers refractory consumption. Although the technology works in series with the process, its implementation can be in parallel, while the steel mill is in operation.

The ARCARE® system is the answer for needed holistic approach to achieve higher production with reduced graphite and refractory consumption, reduced maintenance cost and higher efficiency.

**Keywords:** ARCARE, SPLC, Electric Arc Furnace, Power stabilization, Electrode consumption, Reduced refractory

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**Introduction:**

**AC furnace operation**

A conventional alternating current electric arc furnace (AC EAF) operates with impedance control. Current and power control are achieved through an on-load tap changer within the furnace transformer and the electrode control by hydraulic system.

Power is proportional to the furnace transformer voltage squared, and inversely proportional to the furnace system impedance.

Arc impedance variations are inherent, irrespective of steel scrap melting, direct reduced iron (DRI) and hot briquette iron (HBI) melting or submerged arc furnaces for nonferrous applications. Such impedance variations result in current and power fluctuation. The electrode control, due to the mass of the system, is too slow to compensate for arc impedance variations. This leads to current and power swings and the average power remains much lower than the peak power swings.

**Holistic approach**

Holistic approach for productivity, efficiency and flexibility needs to take into considerations not only the normal arc behaviour but also the geometry of furnace, scarp charging systems, operational constrains which strongly influence refractory maintenance, power profiles to suit scrap mix, etc. The economics of operating costs are very important for viable operation of plant. The electrical power supply must let plant operate with different mix of electrical and chemical energy, without affecting productivity and overall efficiency.

**Sizing of electrical system**

The outcome of current swings are seen at the design stage, as well as during operation. During design the electrical system is over-sized. The ARCARE® system is capable of utilizing this built-in margin to increase production and reduce operating cost.

**Graphite saving**

The above mentioned current swings can result in resonances in the electrode or its arm and lead to electrode breaks. This results in higher electrode consumption and unplanned loss of production.

Current swings cause additional heating of the electrode tip and accelerate the butt loss, thus increasing electrode consumption.

The ARCARE® system, allows for operating longer arcs on lower current thus decreasing the electrode consumption. With today’s increased graphite cost, this supports the reduction of production cost.
Refractory consumption

Refractory consumption can be reduced through minimal power swings and reduced furnace hot spots as a result of balanced impedances in all phases. Additionally, system related hot spots, due to the design of the furnace or the electrical system, can be eliminated by running the optimal power on individual electrodes.

In case of shaft furnaces, geometry of electrodes and charging practices technically also play an important role for refractory temperatures and thus its wear and tear. In case of continuous scrap charging or batch charging (like in a shaft furnace) temperature is not uniform in the shell. Near to scrap changing point the temperature remains quite cold while away from it, the electrode and the refractories get over heated. ARCare® system allows individually controlled voltage and current in the hot area which will reduce refractory consumption significantly. This will avoid frequent refractory replacement there by resulting in extra melting hours.

Transformer utilization

One way to increase the utilization factor of the transformer is to reduce the current swings, stabilize the arc and operate at the highest possible voltage to get more power across the arc. This is the easiest way by which we can get more from the installed base.

Reduced tap changer operation

ARCare® system reduces furnace transformer tap changer operation up to 75%. This gives prolonged use of tap changer without maintenance, which saves operational cost.

Water-cooled cable

During operation, normal current swings produce unwanted vibrations and a lot of up and down movement of the electrode arm, which, in turn, increases the mechanical maintenance on the current conducting equipment, such as the electrode arms or furnace cables.

The stable current minimizes the forces on the water-cooled cables. This minimizes the cable breakages, increases in general the cable life and reduces the cable replacement costs.
**ARCare® Technology:**

ARCare® combines Hatch SPLCTM technology with the vast experience of ABB in power electronics and furnace power supplies. The result is a system that introduces a variable controlled reactor on the primary side of the furnace transformer and therefore tackles the current swings at source.

This means that in an ARCare® system, the current and voltage are individually controlled by means of the thyristor stack and the electrode hydraulics. The response of the current control is based on predictive controls, the logic of which continuously monitors arc current and acts in advance within 20 to 30 milliseconds so that the furnace current is kept constant.

The ability to act in advance is the result of fast current control provided by the thyristor stack, compared to that of a hydraulic system moving the mass of an electrode which takes hundreds of milliseconds. Higher average power into the furnace reduces power-on time resulting in higher steel production and lower energy, electrode and refractory consumption per ton of produced steel.

As the ARCare® system is installed in the switchyard, where real estate is readily available, and as it operates in parallel with the existing system, it can be installed without a major shutdown. Plant operation, therefore, continues without any
additional downtime. System configuration is such that changeover of plant operation, with or without the ARCADE®, takes place within a few minutes.

Figure 2 Thyristor stack  
Figure 3 Comparison of electrode current

Operating scenarios

ARCADE® reduces current swings significantly and increases the stable current operating range. With the ARCADE®, therefore, stable operation is achieved with both lower and higher current. The furnace can operate at a higher power with a stable arc without over-loading the transformer and associated electrical system. The power profile can be modified by using ARCADE® to operate the transformer and furnace at rated capacity. A significant increase in steel production is achievable.

Reduced power-on time lowers radiation losses, electrode oxidation and tip consumption and refractory consumption and hot spots. Fewer current swings reduces vibrations and reduces electrode up and down movement, thus less wear and tear on the hydraulic system and the gantry, resulting in lower maintenance costs. To achieve a higher maximum operating power, normally a higher voltage tap or lower series inductance is needed. Higher average power, during bore-in and meltdown, can usually be achieved resulting in constant higher power over the entire melting cycle.

The current clipping ability of the ARCADE® system allows the furnace to operate at higher power due to a longer arc at the same, or even at lower current. Improved stability of the current and the arc, provides stable operation at higher voltage resulting higher power, without any risk of roof or side wall arcing.

Stable current helps to meet the network requirements without having to increase the existing compensation equipment. The target is to modify the melt program of various stages to reduce the power-on time at improved arc stability.
Individual electrode current control limiting eliminates over heating of refractories where the metal is very hot. This is very useful in shaft type furnaces. Individual voltage control reduces flairs to the side wall and the roof, resulting in longer panel life and higher furnace availability.

Static current control minimizes the tap changer operations.

ARCARE® allows flexible power profile during boring, melting as well as during refining.

**Estimated performance values**

Based on classical calculations for the power-on time, electrode and energy consumption, the following parameters can be estimated:

**Reduced power-on time due to power increase:**

As the energy needed for a defined amount of scrap to be transferred from solid to liquid at a defined temperature is constant, the reduction in power-on time can be calculated via the required energy and the increased average power.

By taking measurements on site, the furnace power curve, in relation to the current is calibrated. Thus, an estimation of what the system can deliver with the ARCARE® in operation can be determined. Figure 4 shows an example for one operating point.

Increased average power translates into faster melting due to higher energy transfer in a shorter time.

If the voltage can be increased, a significant increase in maximum power can be achieved.

This translates into a production increase by suitably changing melt program.
Reduced electrical energy consumption:

One way to estimate the benefit in energy consumption is to use the formula developed by S. Köhle based on a survey of 14 furnaces.\(^1\)

\[
\frac{WR}{kWh/t} = 300 + 900\left[\frac{GE}{GA} - 1\right] + 1600\frac{GZ}{GA} + 0.7\left[\frac{TA}{oC} - 1600\right] \\
+ 0.85 \frac{t_s + t_n}{\text{min}} - 8 \frac{MG}{m^3/t} - 4.3 \frac{ML}{m^3/t}
\]

If we assume that all parameters in Köhle’s formula remain the same except the power-on time, the formulae can be reduced to:

\[
\text{El. Energy improvement} = W_{r\text{old}} - W_{r\text{new}} = 0.85 \times \frac{(ts_{\text{old}} - ts_{\text{new}})}{[\text{minutes}]} \times \left[\frac{kWh}{t}\right]
\]

Depending on the achieved power-on time, reduction in electrical energy savings can be realized.

Reduced electrode consumption:

According to the following formulas from B. Baumann \(^2\) the electrode consumption takes place at the tip and at the side walls.

\[
E_T = N_E \cdot I_E \cdot F_T \cdot \frac{t_s}{G_A} \quad \quad E_S = [N_E \cdot L_S \cdot \pi \cdot \frac{D_E + D_T}{2}] \cdot F_S \cdot \frac{t_s + t_n}{G_A}
\]

The total electrode consumption is the sum of the side and tip consumption.

\[
E_R = E_T + E_S
\]

- \(N_E\) number of electrodes
- \(G_A\) furnace tap weight
- \(I_E\) electrode current
- \(L_S\) oxidising electrode length (≈ 3 m; see below)
- \(F_T\) tip factor (0.013 kg/h/kA²)
- \(D_E\) electrode nominal diameter; \(D_T/D_E \approx 0.68\) for AC
- \(t_s\) power-on time
- \(D_T\) electrode tip diameter
- \(t_n\) power-off time
- \(F_S\) side oxidation factor (≥ 6 kg/h/m²)

Based on the above formulae it can be seen that the tip consumption varies due to the power-on time and the value of the electrode current; as the tap weight, tip factor
and number of electrodes are not changed by the introduction of an ARCARE®

system. For the side consumption the power-on and power off time is relevant, means the total time the hot part of the electrode is exposed to oxidation.

Taking into consideration the expected power-on time reduction, the effect of the stabilized and balanced current and the new value of the average current with ARCARE®, an estimate can be made on how much the electrode consumption can be reduced.

Reduces refractory consumption

Refractory consumption decreases due to the elimination of hot spots in the furnace as a result of unequal power in the individual electrodes is corrected. Generally, the furnace lifetime will be increased as the roof and sidewalls are less stressed due to partial overheating. Sudden exposures of the arc can be handled by reduction of power on individual electrodes without tripping the furnace and thus gaining on furnace up time. ARCARE® allows controlled current and voltage in the area where refractory erosion is high due to uneven feed.

Results achieved from Pilot plant:

ABB commissioned 1st ARCARE® system in USA which is in operation for more than 24 months.

The average power was increased by 5%
The maximum power was increased by 10%
Power on time was reduced by 1 minute
Electrical energy consumption reduced by 1%
Hot spots eliminated, leading to higher average power and reduced gunning and thus lower tap to tap time and higher furnace availability
Heavily reduced maintenance on the gantry and less failures during operation
Electrode breaks reduced heavily (from an average of 6 to less than 1 per month)
Reduced electrode consumption including breaks of 7%
75% reduced operation of the tap changer, thus reduced maintenance cost
In general less damage to furnace and thus increased up time leading to 1 heats more per day in average
The ARCARE® System offers an opportunity to get more out of your installed base with improved efficiency. This technology is ideal for existing AC EAF’s as it can be installed on an operating plant. Installation is possible while plant is in operation, resulting in minimum shutdown.

The ARCARE® System is the answer for demanding production needs and is achieved through flexible power profile requirements of the market, while increasing efficiency.

**Typical benefits**

The following table shows typical values based on a case study for improved performance of a furnace operated with an ARCARE® system:

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average power increase</td>
<td>up to 7%</td>
</tr>
<tr>
<td>Reduction in Tap to Tap time</td>
<td>up to 10%</td>
</tr>
<tr>
<td>Production increase</td>
<td>up to 10%</td>
</tr>
<tr>
<td>Energy consumption saving</td>
<td>in the range of 4 kWh/ton</td>
</tr>
<tr>
<td>Electrode consumption saving</td>
<td>up to 10%</td>
</tr>
<tr>
<td>Electrode breaks due to oscillation</td>
<td>reduced by 50%</td>
</tr>
<tr>
<td>Tap changer operation</td>
<td>up to 75%</td>
</tr>
<tr>
<td>Furnace cable life</td>
<td>increased</td>
</tr>
</tbody>
</table>

The achievable values depend on the reduction of series impedance of the furnace and the ability to increase the secondary voltage of the furnace transformer. To operate sustainable on higher voltage the furnace must offer the ability to increase the slag height if proven to be not sufficient. This varies from site to site.

**Summary of tangible and non-tangible benefits from ARCARE®**

Reduced current swings means constant current and higher average power.
Furnace can be operated at higher voltage with better arc stability.
Reduced power-on time results in increased steel and reduced radiation losses.
Reduced energy consumption due to reduced radiation losses.
Less electrode consumption.
Reduced tap changer operations.
Reduced sidewall and roof arcing leading to reduced refractory consumption.
Reduced hot spots and increased refractory life.
Reduced vibrations means lower maintenance.
Reduced flicker depending upon furnace impedance and achieved power increase.
Allows for flexible operation in terms of output increase or optimized electrode consumption.
Reduced reactive power fluctuations resulting in smaller size of SVC, for same average power.
Less stress on furnace transformer leading to increased lifetime.
Proven ABB power electronics system integrated with Hatch SPLC™ know-how for AR CARE®.
Advanced simulation centre in ABB effectively commissions plant before it is installed at site, in case of complex network situation and requirements.

Conclusion

The AR CARE® system offers an opportunity to get more out of your installed base with improved efficiency, with holistic approach. This technology is ideal for existing AC EAF’s as it can be installed on an operating plant. Installation is possible while plant is in operation, resulting in minimum shutdown.

The AR CARE® system is the answer for demanding production needs and is achieved through flexible power profile requirements of the market, while increasing efficiency.

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Author’s CV:

**Shripad Tambe**, Master of Technology, IIT Kanpur. Started career in 1977 with HBB (Hindustan Brown Boveri) India, where early responsibilities was as a senior research and development manager.

Up to 1999 worked in various technical departments including system engineering, ABB Switzerland.

Inventor of two patents registered in many countries in the area of rectifiers for DC arc furnaces.

Since October 1999 to 2005, worldwide responsible for retrofit, revamp, upgrades of rectifier plants for electrolysis and arc furnaces. DGM, Systems Group and Head of Sales and Projects.

Presently Vice President Regional Sales, DGM Large Projects responsible for rectifier systems for aluminium and DC arc furnaces as well as SVCs for industrial applications.

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From 2001 until 2010 Heading various engineering groups including mechanical and electrical engineering for DC Arc furnaces, SVC systems and aluminium smelters.

Inventor of various patents and utility models in the field of high power rectifiers.

Heading global product management from 2011 until 2016 for high power rectifiers and responsible for ARCARE® as product manager. Currently heading system engineering for high current rectifiers, SVC’s and ARCARE® systems.