Power Profile Optimization in TenarisTamsa’s Electric Arc Furnace

Electrical profile configuration is known to be designed in order to balance voltage, current and reactance. This paper presents the development of tools that were created to improve power profiles in terms of operational and safety issues. This includes a simple model to assess the characteristics of a profile before testing it, and a statistical approach to take advantage of actual temperature measurement from water-cooled panels to optimize thermal behavior in the furnace. With these tools, it has been possible to develop a methodology to make strategic changes like power increase in a safe and fast manner.

The importance of an adequate electrical profile for the electric arc furnace (EAF) is well known, and it’s necessary to take into account the correlation between electrical variables and stable arc operation. High-voltage operation is related to less electrode consumption, which normally is one of the main transformation costs. Nevertheless, voltage is proportional to arc length and will increase arc radiation to furnace walls, which, depending on design, metallic charge and other particularities, could cause undesired effects such as higher refractory wear or safety risks due to water leaks from the water-cooled panels.

The present work describes the tools that were created to modify and optimize TenarisTamsa’s EAF power profiles. It will detail: (1) the development of a simple model based on the furnace’s control systems that allows the creation of profiles and simulates chemical and electrical configurations to calculate main key performance indicators (KPIs), and (2) the characterization of thermal load through the different process stages using the panel’s cooling water temperature and the use of “high-temperature” events to monitor the impact of this effect in a statistically representative manner.

These tools were created and applied during 2016 and 2017 to increase TenarisTamsa’s furnace electrical power to its maximum level to get the highest possible productivity from the installed transformer. Nowadays these tools and approaches are essential to make any adjustments and monitor the process.

Introduction

Characteristics of TenarisTamsa’s EAF — TenarisTamsa’s furnace is a typical tri-phase-alternating current with an eccentric bottom tapping (EBT) system, capacity of 200 tons of liquid steel (40 tons to remain as hot heel and 160 tons as heat size). It has a 135-MVA transformer, one reactor to work with high voltages and a chemical package comprised of four oxygen injectors, four carbon injectors, two lime injectors, six oxy-gas burners, and a supersonic lance both for cleaning slag door and support oxygen injection. Fig. 1 shows the geometry and configuration of the electric arc furnace.

The metallic load is approximately 180 tons, from which around 70% is scrap, 20% pig iron and 10% is pre-reduced. A charge is made through two or three 80 m³ buckets.
for scrap and pig iron, and through a conveyor belt for the pre-reduced (in the present study, three bucket heats were not considered since they represent less than 1% of production). The process is divided into three main stages during power-on: first bucket melting, second bucket melting and refining.

**Cooled Panels Set** — The furnace has a set of water-cooled panels that are divided into 12 positions around its circumference and other three positions (A, B, C) in its vertical component (Figs. 2 and 3).

Each panel has a temperature sensor mounted at the water circuit outlet and it's connected to an alarm system that triggers different protective actions when a limit value is reached. There are three different alarm levels that could deactivate burners, disconnect one phase or disconnect the furnace completely.

Each one of these alarms is also registered as an event, from which is possible to gather valuable statistical information.

**Operation Control** — Power profiles are controlled by an automated system where the user can configure each of the operational modes for chemical and electrical regulation, dividing the process into steps controlled by specific total energy consumption (electrical + chemical). The following parameters are controlled by the automated profiles:

- Transformer tap.
- Reactor tap.
Background

The furnace currently operating at TenarisTamsa’s steel shop was installed during 2012, and in 2013 it reached 90 MW for average heat power, which was when it became necessary to balance the production cycles between melting and casting at the continuous casting machine.

During this first power increase, water leaks coming from cooled panels were occurring frequently. The cause was identified as thermal fatigue cracks due to arc radiation (Fig. 4). Coordinated efforts were taken to overcome this crisis with different actions such as water pressure increase, power profile modifications and a panel material change from steel to copper in critical areas, among others.

In 2016, the continuous casting machine was revamped and a new trimming station installed to increase the steel shop’s productivity. With these modifications, the necessity to take most of the installed transformer and reach the design average power of 97 MW arose. Fig. 5 shows the evolution of average power during 2016 and 2017.

Power Profile Simulator

As it was mentioned previously, TenarisTamsa’s EAF has an automated level 2 system to manage power profiles. This system applies the set configuration to the electrical controller and to each chemical package element following the evolution of total energy (chemical + electrical).

To configure a power profile, there is a module in the proprietary level 2 system that divides the process into three main stages: first bucket melting, second bucket melting and refining. In each of these stages, the user is able to set any number of “steps” (in specific total energy per charged ton) separately for electrical and chemical profiles.

In order to achieve the objective of developing a new profile maximizing productivity, a simulator was developed that allowed different proposals to be created and modeled for use at the industrial level. This power profile simulator was created using an Excel book to perform the required calculations, using the applicable formulas to obtain the main electrical variables. To obtain chemical power, a simplified formula...
was used. The equations used to calculate electrical power are shown in Fig. 6.

This tool receives the same input as the level 2 system and allows the results to be analyzed from configuration changes in terms of energy balance (electrical/chemical), power-on, arc stability, radiation index, etc. Figs. 7–10 show the graphic results given by the simulator.

In addition, it also provides a table with valuable information to adjust and modify power profiles such as power factor, consumptions of gases, insulflated carbon, electrode consumption and average current, among others.

To validate the output provided by the simulator, the calculated results for the 90 MW profile that has been operating since 2013 were considered and compared with the average real values from a sample of 494 heats melted from January to March 2016; just heats with less than 15 minutes of interruption were considered in order to take out any effect from start-ups. Table 1 shows a comparison between real and calculated results, with a difference ranging between 1 and 2%.

### Equations

\[ V_a = \frac{V \cdot \cos \varphi}{\sqrt{3}} \]
\[ I = \frac{V \cdot \sin \varphi}{X \cdot \sqrt{3}} \]
\[ \sin \varphi = \frac{I \cdot X \cdot \sqrt{3}}{V} \]
\[ X = \frac{V \cdot \sin \varphi}{\sqrt{3} \cdot I} \]
\[ P = 3 \cdot V_a \cdot I = 3 \cdot \frac{V \cdot \cos \varphi}{\sqrt{3}} \cdot I = \sqrt{3} \cdot V \cdot I \cdot \cos \varphi \]

Radiation Index (KW · V/cm²) = \( P_a \cdot \frac{V_a}{3} \cdot d^2 \)

\( P_a \) = Active Power

\( d \) = Furnace Wall – Electrode Distance

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**Figure 6**

Equivalent single-phase circuit equations.

**Figure 7**

Electrical configuration (transformer, currents and reactor).

**Figure 8**

Electrical and chemical power.
Due to high-voltage operation, whenever a change in the electrical profile is performed, it is considered critical to maintain control of the radiation to the cooled panels because:

- From past experiences, after a certain number of operations, cooled panels made of steel are affected with transversal cracks, causing small water leaks that, if not detected, lead to refractory hydration with high risk of a shell failure and an uncontrolled spill of steel. If cracks are detected, they are repaired with a loss in productivity.
- A higher exposure to arc radiation will impact in a higher refractory wear mainly in “hot spots” such as in front of the electrode, which decreases the duration of furnace campaigns.
- Higher exposure generates more frequent stoppages: every time one panel reaches the temperature limit, an alarm is activated.

In order to weigh the arc radiation effect, information from the exit water temperature sensors that are installed on each of the panels is used. In Fig. 11, it is possible to see graphical information from each of the 24 water-cooled panels that complete sections A and B from one typical heat. It is possible to distinguish two periods with a temperature increase in some of the panels; these correspond to the end of bucket melting when scrap has lowered, arc begins to be exposed, and foamy slag is not yet working because of the solid phase that is still enough to prevent its formation. If the water temperature of any panel surpasses the configured limit, an alarm event is generated. In the example in Fig. 11, there were no alarms, even though there was a typical temperature increase.

This thermal behavior is considered when a power profile is designed; for example, reducing voltage and power when arc exposure is higher to reduce the probability of an alarm event from occurring and, therefore, limiting wear to the refractory and the water-cooled panels.

Analyzing high-temperature event statistics, it is possible to confirm the trend that was observed in one typical heat. In Fig. 12, a histogram of high-temperature events of 2,693 heats was plotted against power-on time in 5-minute intervals. It can be noted that the highest probabilities to have an event are just the moments that were explained earlier.

This information was also used to characterize hot spots in the furnace by analyzing events by their location depending on the panel that had the rising temperature. The shell was divided into three 120° angular sections corresponding to each electrical phase. From these results, it is evident that there is a heterogeneous heat distribution in the phase 2 section.
which is the most critical in terms of arc radiation exposure.

In order to balance heat distribution, in the new power profiles, the burner close to the phase 2 section remains turned off and was replaced by lime injection in order to protect the wall and take advantage of the higher heat concentration.

Fig. 13 plots the distributions of events from each of the three sections, before and after the modifications of the chemical package mentioned before. As it can be observed, even if it seems to be more balanced, there are still significant differences between the phase 1 and 2 sections with respect to the phase 3 section.

**Design of New Profile**

Premises that were considered for designing the new power profile include:

- Reach maximum power using as high a voltage as possible to minimize electrode consumption.
- Maintain similar sinusoidal power factor as it is calculated for the 90-MW profile in order to not compromise arc stability.
- Maintain similar arc radiation index during high-exposure moments.
- Modify oxygen injection to get a similar electrical and chemical energy consumption.

Based on these premises and with the recommendations of an electric arc furnace expert, the new profile was developed. The moments where there is less arc exposure are ideal to increase power with less importance on the radiation index, which becomes more critical during stages of high arc exposure, as it has been already addressed. Taking this into account and using the simulator, the new profile resulted
with an average power of around 100 MW per heat, which means 10 MW more than the profile used at the moment (90 MW). To calculate potential benefits, productivity was calculated considering technological power-off (bucket charge, EBT preparation and tapping), heat size and average real scrap yield. A summary of this is shown in Table 2.

In Figs. 14 and 15, calculated power and radiation index for both the 90 MW profile and the 100 MW profile are compared. Radiation index during high-arc-exposure moments remains almost the same, with just an average increase of 3%, which is considered negligible and will be confirmed during industrial tests.

**Results**

To validate the results, it was necessary to wait until 2017, due to some issues during second the half of 2016 that prevented to have normal conditions (rainy season, oxygen restrictions, etc.) similar to the last stable period using the 90-MW profile (considered from January to March 2016). So the period between April and May 2017 was considered as standard operations with the new 100 MW profile. One heat from this period compared with one typical heat with the previous 90 MW profile is shown in Fig. 16, where real power and radiation index are plotted against power-on to show the real effect of the new configuration.

In Table 3, the results of using the new profile over the main KPIs and the benefit on productivity are shown. Just heats with 15 minutes or less of interruption time were taken into account in order to take out the effect of start-ups.

Some relevant aspects that could be highlighted from the table are:

- An increase of 16.6 tons per hour was obtained.
- Productivity increase is due to a higher average power and consequent decrease in power-on.
- Electrical and chemical consumptions are similar in both scenarios, achieving the set objective.
- Alarm ratio, which is the number of high-temperature events in a given period divided by the number of heats produced in the same period, is even lower with the 100-MW profile.
Calculated average power between 90 and 100 MW against total energy per charged ton.

Calculated radiation index between 90 and 100 MW profiles against total energy per charged ton. (Red shadow correspond to high arc exposure moments and green shadow when the arc is covered by scrap or foamy slag.)
Conclusions

Applying a structured and ordered strategy, it was possible to achieve positive results in a smoothly with minimal risks. An increase of 9.8% in productivity was reached, which is higher than expected, maintaining the same level of energy consumption and even a smaller alarm ratio. The created simulator and the analysis of high-temperature events are very powerful tools to perform process optimization and keep process performance under continuous control.

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Reference


Table 3

<table>
<thead>
<tr>
<th>KPI Comparison Between Operation With 90 MW and 100 MW Profiles</th>
<th>Calculated 90 MW</th>
<th>Calculated 100 MW</th>
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<tbody>
<tr>
<td>Sample (No. of heats)</td>
<td>494</td>
<td>575</td>
</tr>
<tr>
<td>Power on (minutes)</td>
<td>45.1</td>
<td>40.5</td>
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<tr>
<td>Average power (MW)</td>
<td>90.3</td>
<td>100.5</td>
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<tr>
<td>O₂ consumption (Nm³/ton)</td>
<td>36.8</td>
<td>37</td>
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<tr>
<td>Electrical consumption (kWh/ton)</td>
<td>418</td>
<td>415.1</td>
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<td>Liquid ton per heat</td>
<td>162.2</td>
<td>163.3</td>
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<tr>
<td>Power off (minutes)</td>
<td>12.3</td>
<td>12.1</td>
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<tr>
<td>Productivity (tons/hour)*</td>
<td>169.7</td>
<td>186.3</td>
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<tr>
<td>High-temperature alarm rate**</td>
<td>0.35</td>
<td>0.17</td>
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</tbody>
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*16.6 tons/hour increase  
**Alarm ratio (No. events/No. heats)