Q-ONE®, THE DIGITAL STEELMAKING REVOLUTION. POWER ELECTRONICS FOR ARC CONTROL*

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Abstract
Conceived as innovative solution to supply the AC Electric Arc Furnaces, Q-ONE is a Danieli Automation's designed and patented equipment that uses latest power electronics technology to handle irregular loads in a more flexible and reliable way, and values of power factor close to unity. Q-ONE extends the Power System products range to the high-power systems used for EAF.
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1 INTRODUCTION

The electric arc furnace (EAF) technology has seen a continuous evolution in the last 50 years towards increased efficiency, with halved electric energy consumption, a four-time lower tap-to-tap time, electrodes consumption reduced more than five times (figure 1). These results have been achieved thanks to a combination of added chemical packages (oxygen blowing, burners), design improvement (water-cooled walls, EBT, lances, bottom stirring) and enhanced process controls.

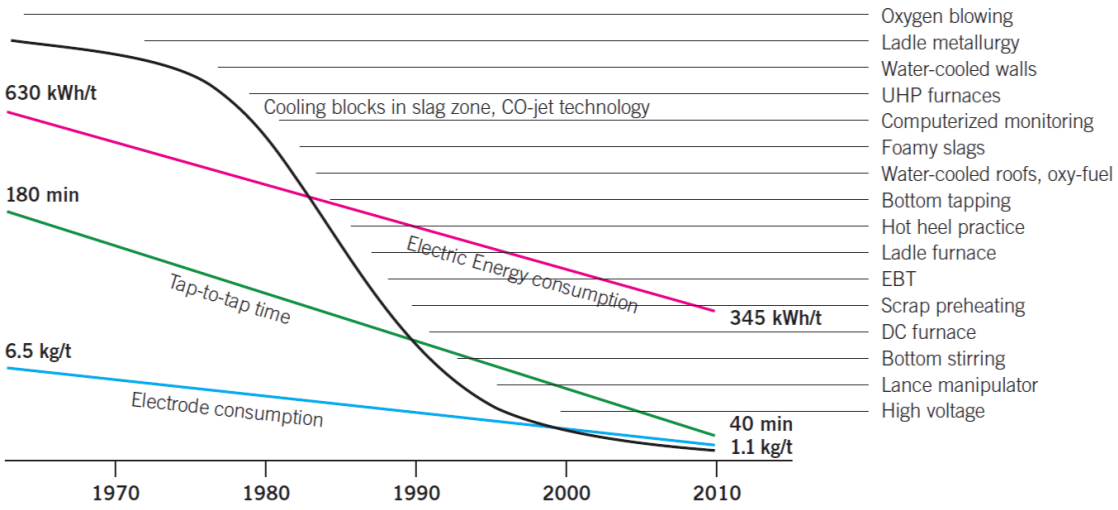

Figure 1 - EAF evolution

Another important tendency is the increase of maximum power for a single furnace, which has led to the development of EAFs capable of producing up to 300 tons of tap steel.

The technological evolution of arc furnaces has not impacted on the solution for power supply of AC electrical furnace, that has remained practically the same for years.

An electric arc furnace has a strong and negative impact on the electric grid. The electric arc melting process generates rapid changes in absorbed power that occur especially in the initial phase of melting, during which the critical condition of an interrupted arc may become a short circuit or an open circuit. Most common effects are flicker, harmonic distortions and the generation of reactive power. Obviously, such effects are magnified by the size of the furnace.

Flicker is a phenomenon characterized by quick voltage variations that are visible on lamps (with a flickering), but that can also affect power electronics, such as inverters in a rolling mill. Arc operation is impacting on the current and voltage harmonics,

determining the harmonic distortion which might influence the behavior of auxiliary electric loads, to the point of even causing machine stops. The transfer of power from the electrical network to the scrap metal to be melted generates a quantity of reactive power that produces heat. This energy is just going to heat the electric cables, and as an immediate consequence there is inevitably a reduction in capacity of energy transfer.

Usually, the energy is measured at the transformer secondary circuit, while the energy that is actually paid is measured in the substation.
Power factor expresses the energy efficiency, meaning the ratio between working power and apparent power, and in traditional furnace operation it can be easily below 80%.

To reduce such effects on the electric grid, many solutions have been developed, superimposing a power system to dynamically compensate such disturbances, namely SVC (Static Var Compensator) and Voltage Source Converter SVC, also called Statcom, which however brings no direct benefit to the transmission of energy to the furnace.

2 METHODOLOGY

A breakthrough technology

In 2016 Danieli Automation installed the first Q-One, the first application of power electronics to control arc current and voltage in the EAF. In other words, using the conventional furnace design, this solution can control and impose arc current, with consequent benefits in process stability and drastically reduced impact on the connecting electric network.

In fact, Q-One operates with a power factor at medium voltage above 0.95, meaning that almost all apparent power becomes working power, generates an extremely low flicker, avoiding the use of compensation systems, also because harmonic generation is well below IEEE limits.

The system is modular by design: not only the needed power can be adjusted by selecting the number of modules, but the solution can be designed for a progressive growth in stages, meaning that initial power can be increased just by adding modules at a later stage.

This modularity also improves reliability and system availability, considering the possibility to produce at reduced power (disabling one module) or even with two phases instead of three.

Considering the need for high availability, modules have also been designed with the same components and inverters, which minimizes the quantity and value of spare parts. The digital control allows also for remote monitoring and troubleshooting.

The working points are no longer dictated by the taps on a transformer but can be freely chosen based on process needs.

One additional degree of freedom and process control opportunity is granted by the frequency change, possible in arc furnaces only with Q-One. A frequency higher than the network nominal improves arc stability, therefore is used during boring stage. On the other hand, a below-nominal frequency, down to 20Hz, was already tested, and it is perfect to reduce energy consumption in the refining stage and a deeper penetration of arc in the bath.

Going hand in hand with hybrid Q-One fits very well sustainable steelmaking, being able to connect the DC Link to renewable energy sources, such as photovoltaic but also hydro or wind power.

With hybrid feeding, the OpEx of a furnace can be further improved, not to mention the reduction of carbon footprint. A software suite, named Q3-Jenius, has already been designed to manage the different available sources, depending on their cost and availability, also accounting for forecast energy consumption for specific products.

An integrated intelligent suite

The unique, reliable, and flexible green power solution also benefits AI applications and advanced control solutions. In fact, Danieli Digimelter offers dynamic and automatic melting profile adjustment, thanks to Q-Melt, designed with the Danieli Intelligent Plant architecture for continuous learning and process improvement.

Automatic scrap yard management, with connection to melting process control, ensures accurate and consistent working points set up and quality assignment. To conclude, the control pulpit is ergonomically designed to integrate human expertise and machine precision to achieve unique performance and superior quality with the best cost strategy.

These results are achieved with a no man-on-the-floor philosophy, powered by the advanced automation and the adoption of robots on the field to perform dangerous and repetitive operations, to achieve safe steelmaking operations.

3 RESULTS AND DISCUSSIONS

Case study: ABS Sisak

Figure 2 - ABS Sisak Q-ONE installation

In summer 2019 ABS Sisak, a 78-t melt shop for special steel in Croatia, equipped its Electric Arc Furnace with the innovative Danieli's Q-ONE system (Figure 2).

The Q-ONE technology at ABS Sisak, in a 4-modules configuration for a total capacity of 42 + 20% MVA, has replaced the original 60 + 10% MVA furnace transformer, to comply with the new and stringent rules for flicker control applied by the Croatian electrical energy supplier.

More than one year after the startup, the main strength of the system has been confirmed by power factors always close to 0.97 and by a flicker generation now acceptable for all typical operations - even with temporarily reduced network short-circuit power. The low emission of flicker with Q-One was certified by the local electrical energy supplier, giving the possibility to ABS Sisak, devoid of a compensation system, to continue the operations, following the strict rules of the Croatian electric authority.

In addition, the Q-ONE has promoted an important process optimization in terms of furnace productivity and electrode consumption. Compared to the baseline before new system installation, a productivity increase of 10% and electrode savings of more than 15% have been confirmed over a long-run period.

Figure 3 - Flicker trend at ABS Sisak

A test campaign has been organized at ABS Sisak, to verify features which Q-ONE can provide, while existing technologies do not allow them. With the Q-ONE we have the possibility of working at different electrical frequencies and melting under unbalanced phases conditions.

Conventional electric arc furnaces are powered by commercial frequency alternating current. This means that electrical frequency right now is a fixed value imposed by the grid electrical system. Thanks to Q-ONE and the digital control of the power units, for the first time ever at the industrial scale, the operating frequency of the arc can be changed independently from the network value, thereby allowing the freedom to select the most suitable arc frequency to ensure the best EAF performance. In practical operations, by increasing the frequency it is possible to improve the arc stability and maximize the power transfer; frequency increase perfectly fits the irregular operations of the scrap boring phase where an improved arc stability leads to a reduction of power-on time.

On the other hand, by reducing the arc frequency it is possible to drastically reduce the amount of reactive power on the secondary side, thus reducing the overall necessary power and minimizing the electrical losses.

To define the best frequency during each melting step, the tests carried out at ABS Sisak have been performed with the frequency ranging from 40 to more than 70 Hz (but lower frequency down to 20Hz have already been successfully tested in other Q-ONE plants with benefit for further reduction in energy consumption).

After the first trials, the positive effects of working at a different frequency have been immediately translated into significant power-on time and electric consumption reduction. In the specific case of ABS Sisak, operating at variable frequency has led to a power-on time reduction of approx. 5%, determining an approx. 3% reduction in electric energy consumption.

Detailed analysis has confirmed the savings are directly attributed to the improved arc stability and reduced scrap boring period.

In the LRF in Tokyo Steel, reduction of frequency from the nominal 60Hz, where already 5% savings on power consumption were noted, to 30 and even 20Hz has brought the savings on energy consumption to an excellent 14% compared to previous operation with the traditional transformer solution.

Besides the variation of arc frequency tests, a second group of heats have been dedicated to the optimization of the melting behavior under unbalanced phase conditions. Traditionally, the electrode phases powered by tri-phase transformers can be unbalanced within a limited range, as energy withdrawal from the network easily becomes unacceptably unbalanced and an earnest effort is therefore required to compensate for it.

Thanks to the exceptional flexibility of the Q-ONE system, it is possible not only to set different arc lengths between each phase but also to dynamically define the proper unbalancing along the heat progress according to the different melting steps and conditions.

Different from conventional transformer systems, where the electric arc settings in terms of power, voltage and current are shared between all the phases, Q-ONE technology makes it possible to set the working points for each electrode phase independently and therefore redistribute the power in the shell according to real needs, to promote the most effective melting or avoid overheating and energy loss. During the tests at ABS Sisak, a phase unbalancing of +14%/-27%/+14% respectively, has been achieved without any impact on the electrical figures such as power factor, flicker, and harmonic distortion on the medium voltage (figure 5)

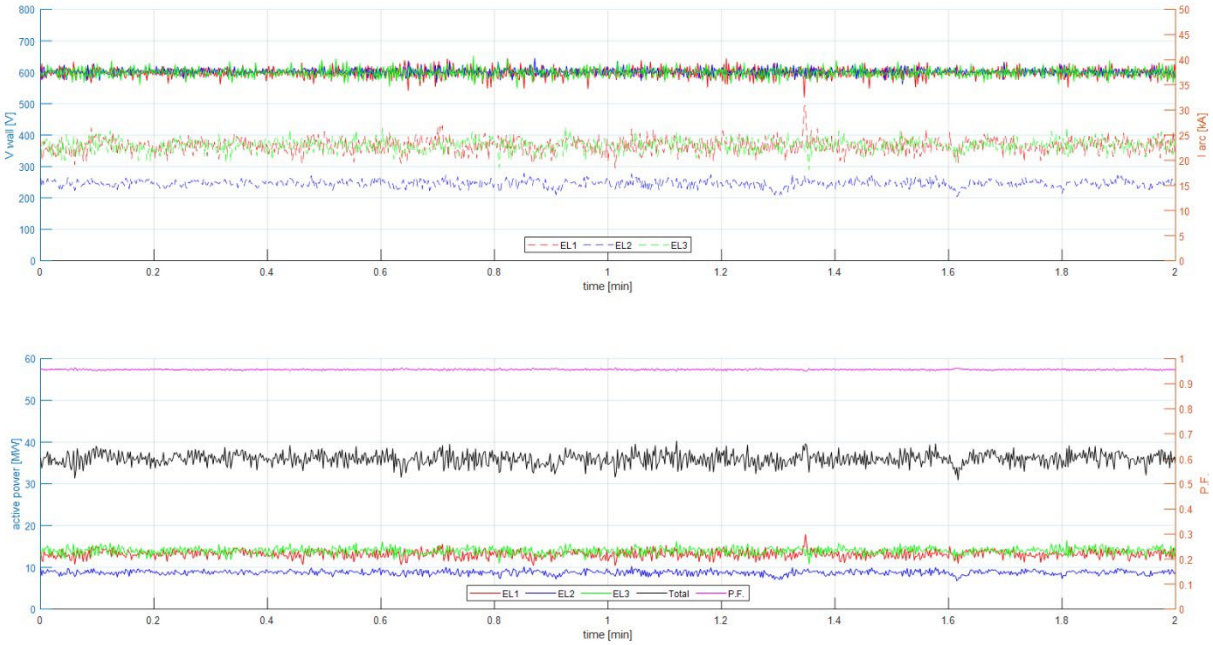

Figure 4 - Phase unbalancing achieved at ABS Sisak

Summarizing, the test sessions held at ABS Sisak once again have shown the ability of both the Q-ONE technology in terms of flexibility and performance: the new features have demonstrated brilliant potential in process optimization and cost savings without any application limitation to different charge mixes or furnace designs.

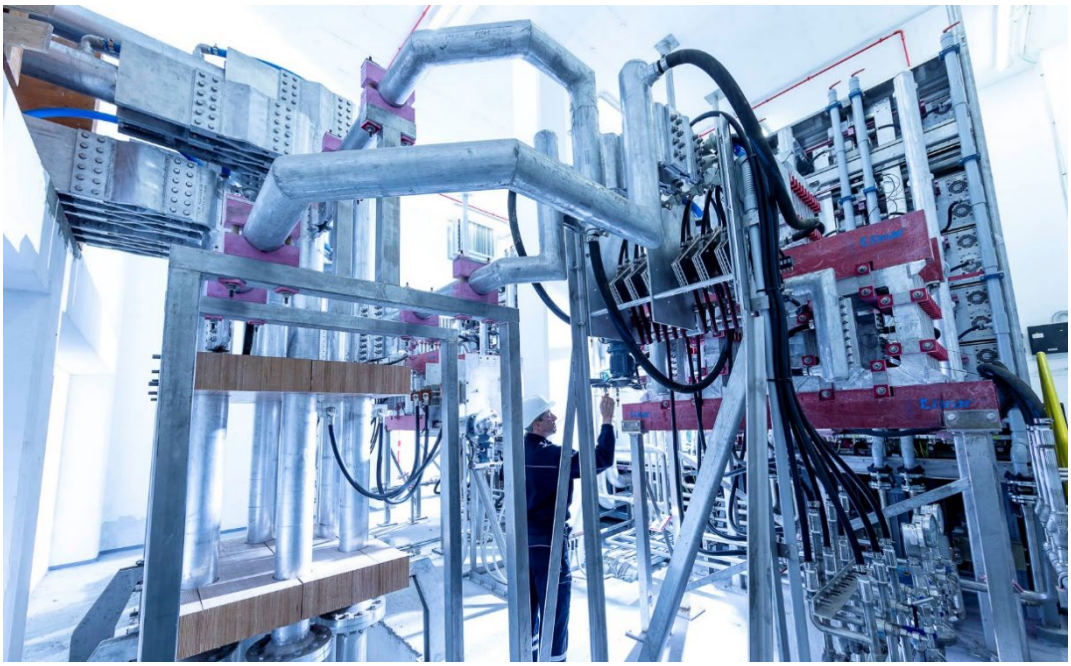

Figure 5 - QONE Busbar

Figure 6 - QONE Modules

4 CONCLUSION

Q-ONE technology, developed and patented by DANIELI, represents a breakthrough innovation in power transfer to the arc furnace. The possibility to control arc current and voltage and the design of the solution ensure improved furnace performances, reduced electric consumption, longer refractory life, and less electrode consumption. Thanks to the technology adopted, the impact on the grid is minimized compared to the traditional solution, avoiding the need of additional compensation systems.

On top of this the Q-ONE is the only technology allowing for direct connection of renewable energy sources such as photovoltaic to the melting unit (to the Q-ONE DC Link), opening an exciting opportunity for an even more sustainable and digital melting process.

Last but not least, this is the only technological solution allowing for frequency variation in the arc, adding one more degree of freedom in the determination of the working points and empowering process control.

In conclusion, Q-ONE power converters offer unmatched power control and handling, with much better arc stability, thanks to the use of latest power electronics technology to handle irregular loads and allowing a Hybrid feeding (electric grid + renewable energy) of the Arc Furnace.

More than 30 references (beginning of 2023) prove the exceptional interest in this innovation in steelmaking.

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