

Improving power quality in a Steel Mill in Colombia

Abstract – In collaboration with a local partner *Bulla y Salcedo ingeniería*, Merus Power supplied a Static Synchronous Compensator (STATCOM) to a steel plant in Colombia. The primary loads of the plant are a 45 MVA Electric Arc Furnace (EAF) and a 12 MVA Ladle Furnace (LF) connected to a common 26.4 kV MV bus.

The Colombian grid code specifies power factor limits at the point of common coupling (PCC). EAFs typically operate with a low power factor to enhance the stability of the steel melting process, and therefore may not comply with the issued grid requirements. Consequently, reactive power compensation, such as a Merus® STATCOM, is often required to meet the grid code requirements. The rapid fluctuations in the reactive power flow of the furnace also lead to other power quality issues, such as flicker emissions which can also be mitigated using a Merus® STATCOM.

To overcome these power quality issues, Merus Power delivered a Merus® STATCOM solution, consisting of four Merus® M2000 STATCOM modules, a filter capacitor bank tuned to the 2nd harmonic (120 Hz) and a control and protection system. The provided system can control its reactive power output in real-time between 0 MVar and 15 MVar (capacitive), depending on the requirement of the system.

In this study the effects of the installed Merus® STATCOM solution are discussed. In addition to the required power factor correction in PCC, the installed Merus® STATCOM also enhances the steel melting process by stabilizing the voltage in the medium voltage busbar leading to shorter melting times.

1. Customer electrical system and challenges

The most prominent loads of the customer's steel plant are an EAF rated at 45 MVA and an LF rated at 12 MVA. Both furnaces are connected to a common medium voltage bus with a nominal voltage of 26.4 kV. The medium voltage bus is fed by two parallel main transformers, each rated at 42 MVA, which are connected to the 115 kV HV bus.

Furnaces consume large amounts of reactive power during operation to keep the process stable. In furnaces, an arc is formed between the electrodes and the scrap. When the furnace consumes reactive power, there is a

phase difference between voltages and currents. This means that current and voltage do not reach zero simultaneously, which could potentially extinguish the arc. From a process standpoint, the optimal solution would be to operate the furnace with a low power factor.

However, the grid operator sets limits for the reactive power emissions in the grid code. Therefore, to comply with grid code requirements and maintain an efficient melting process, steel plant operators must invest in reactive power compensation. Reactive power compensators, such as a Merus® STATCOM, offer additional benefits to the steel melting process, which are also discussed in this study. The primary function of the Merus® STATCOM is to compensate for the global reactive power of the plant.

Under Resolution CREG 015 of 2018, issued by Colombia's Energy and Gas Regulatory Commission (CREG), strict operational limits are established regarding the exchange of reactive power between grid operators (ORs) and end-use consumers or network users. The primary objective of these limits is to maintain grid stability, ensure power quality, and optimize the available capacity of the National Transmission System (STN) and Regional Transmission Systems (STR).

The regulation sets a inductive reactive energy threshold based on a power factor limit of 0.90. Specifically, inductive reactive power transport is free of penalization as long as the ratio of reactive energy (Q_L) to active energy (P) does not exceed 0.4843 during any hourly interval, which corresponds mathematically to $\tan(\arccos(0.90))$. Any inductive reactive energy drawn beyond this threshold is deemed an excessive consumption that degrades voltage stability and increases line losses across the distribution network.

Furthermore, CREG Resolution 015 of 2018 strictly penalizes the injection of capacitive reactive energy (Q_C) into the grid, regardless of the active power demand at that moment. Transporting capacitive reactive power into the system can cause unwanted voltage rises (Ferranti effect) during low-load periods and disrupt regional voltage control strategies. Consequently, all injected capacitive reactive power is subject to penalization from the very first unit of energy ($kVARh$).

To enforce compliance, CREG introduced a progressive financial mechanism through the variable tariff surcharge *M*. Under this framework, persistent non-compliance—defined as exceeding inductive limits or injecting capacitive reactive energy during more than 10 days in a calendar month—results in a step-up multiplier that increases the financial penalty applied to every excess *kVARh*. This structure incentivizes network users to install dynamic power factor correction systems, such as automatically switched capacitor banks or STATCOMs, directly at their connection points.

2. Merus® Solution: 0 MVar (ind) to 15 MVar (cap) STATCOM system

Merus Power delivered a Merus® STATCOM system consisting of four Merus® M2000 STATCOM modules, a filter capacitor bank and a control & protection system. The compensation system was connected to the 26.4 kV medium voltage network. Reactive power from the STATCOM modules can be continuously controlled within a range of +/- 7.5 MVar depending on the requirement of the system. As industrial loads are typically inductive in nature, capacitive reactive power is mostly needed from the compensator. The filter capacitor bank, being a constant impedance load, primarily maintains a steady capacitive reactive power output. It only varies if there are changes in the bus voltage. The filter capacitor bank was also tuned to the 2nd harmonic to filter harmonics caused by the furnaces.

The simplified single-line diagram of the system with the Merus® STATCOM is presented in Figure 1.

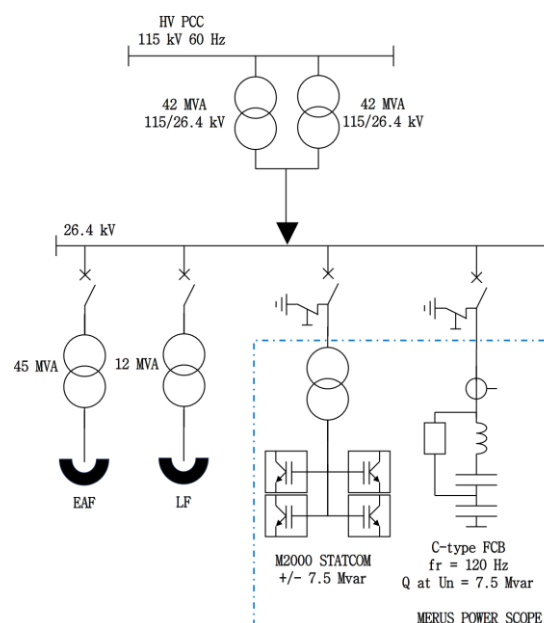


Figure 1 Simplified Single-line diagram of the system and the provided Merus® STATCOM solution

The scope of Merus Power is also presented in Figure 1. In addition, Merus Power also delivered a control and protection system, all busbars and ensured the integration of the STATCOM to the customer's system. In addition to the equipment delivery, Merus Power also carried out testing of the equipment and system studies to ensure that the equipment will reach the desired power quality parameters.

2.1 Technical specification

Table 1 Compensation system specification.

Reactive power, continuous	0 MVar (ind) - 15 MVar (cap) at 26.4 kV 60 Hz
PCC nominal voltage	115 kV
Nominal frequency	60 Hz
Outdoor ambient temperature	0°C - +40°C
Pollution degree	Very heavy

2.2 Control and Protection System (C&P)

The Integrated C&P includes control and protection of the STATCOM modules, the filter capacitor bank, and cooling systems. The entire C&P is placed in a cubicle shown in Figure 2.



Figure 2 Integrated Merus® C&P.

The core of the control system is a high-performance DSP / FPGA board. This processor family is widely used in industrial, medical, and military applications. The control and protection tasks have been shared between the processors so that the best features of each processor type have been utilized. The DSP has been allocated for complex floating-point calculations, thermal protection, and communications operations. The FPGA has been allocated for firing pulse control of the IGBT power electronic switches of the STATCOM modules. The control system incorporates Siemens S7-1500-series PLC, which takes care of the pre-defined logical operations of the compensation system.

The control system contains different control methods. The open-loop control method is based on reactive power measurement of the EAF and LF loads. This enables a fast response to reactive power changes at loads. The open-loop compensation aims to compensate for the rapid reactive power variations caused by the loads. The closed-loop control is based on the reactive power measurement from the PCC. The closed-loop

compensation aims to maintain the pre-set power factor at the PCC.

An essential part of the Control and Protection system is the Supervisory Control and Data Acquisition (Merus® SCADA), which enables the communication between user and STATCOM system. The SCADA interface is shown in Figure 3.

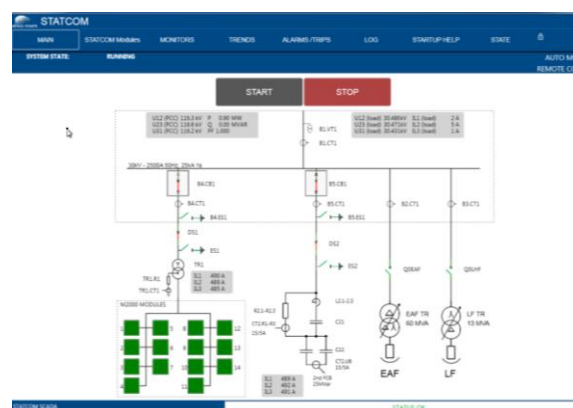


Figure 3 Merus® STATCOM SCADA interface.

2.3 Merus® STATCOM modules

The core of Merus® STATCOM system consists of Merus® M2000 STATCOM modules. These high-power modular units are operated as a controlled current source to provide desired reactive power and harmonic currents in real-time.



Figure 4 Merus® M2000 STATCOM modules.

Merus® STATCOM modules are designed for the most demanding industrial applications. In addition to EAF applications, these are used in other dynamic reactive power compensation applications and harmonic filtering applications, such as compensating shredders, crushers, mine winders, conveyors, and rolling mills. Almost instantaneous response times allow real-time voltage stabilization, power factor improvements, and excellent flicker reduction.

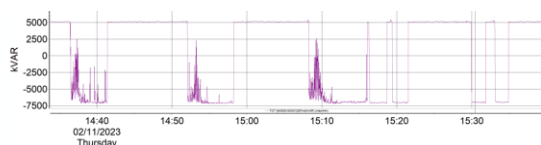


Figure 5-1 Merus® M2000 Modules Behavior

Based on the reactive power measurements shown in the Figure 6-1, the M2000 dynamic modules behavior demonstrates precise and near-instantaneous reactive power compensation, moving between inductive and capacitive states.

The Merus® M2000 modules exhibits remarkable speed, instantaneously transitioning its behavior from inductive to capacitive power in response to the dynamic needs of the EAF. This quick reaction time is a key advantage for maintaining the voltage under admissible limits. The figure shows periods where the M2000 modules generates a positive kVAR value (e.g., above 5000 kVAR). During

these intervals, the STATCOM is operating in an inductive mode. The specific purpose of this operation is to cancel out the excessive capacitive effect that would otherwise be introduced by a traditional capacitor bank. This effective cancellation keeps the system's power factor within an optimal range.

At other times, the M2000 modules switches to a capacitive mode, generating negative kVAR values (e.g., around -7500 kVAR). Crucially, during these periods, the STATCOM's output very closely follows the erratic and demanding reactive power behavior typical of an electric arc furnace (EAF) with extraordinary precision. This indicates the STATCOM is effectively providing dynamic power compensation, mitigating the disruptive voltage fluctuations and harmonic distortions caused by the furnace's operation.

2.4 Filter capacitor bank

Filter capacitor banks are part of the STATCOM system. These provide static reactive power in the most cost-efficient way. Capacitor banks are used since, in most cases, the loads are mostly inductive. Capacitor banks not only provide reactive power but are also tuned to filter some selected harmonic currents.



Figure 7 Photo of the Merus® STATCOM system on site.

In this project, one filter capacitor bank of 7.5 MVar was installed. Merus Power integrated the capacitor bank to operate as a part of the new STATCOM system. By integrating a capacitor bank with the M2000 modules, the system can achieve a total capacitive output ranging from 0 to 15 MVar.

3. Results

Power quality parameters were measured from the site after the commissioning of the STATCOM, and the results are presented in this chapter. The measurements were

taken from the medium voltage bus and the PCC using a Dranetz HDPQ – power quality analyzer.

3.1 Active and reactive power

The reactive power of the furnace varies between different melts, leading to a rapid change in reactive power demand. Merus® STATCOM can fulfill the demand of the furnace rapidly, leading to minimized effects on the network's voltage. In **Figure 8** simultaneous measurements from the STATCOM feeder and the furnace feeder are presented.



Figure 8 Furnace and STATCOM module reactive powers during furnace operation. The reactive power of the furnace (orange) fluctuates rapidly and unpredictably, but Merus® STATCOM (blue) can react almost instantly and control its' reactive power output as needed.

When the furnace is turned on, its' reactive power flow presented in orange starts to fluctuate heavily. To compensate for this fluctuation, Merus® STATCOM responds in an instant. The reactive power from Merus® STATCOM's modules are presented as a blue graph in the figure. When the furnace is turned off, the M2000 modules are mostly compensating for the reactive power of the filter capacitor banks, mitigating the reactive power transferred to the grid.

According to the local grid code requirements, penalties are imposed if the user registers a consumption of inductive reactive energy at their point of metering greater than fifty percent of the active energy that is delivered in each period of measurement. Moreover, penalties are imposed if any capacitive reactive power is fed to the grid in any situation, or any inductive reactive power is fed when the active power is zero. By using these grid code

requirements, a displacement power factor requirement can be calculated using

$$\cos \varphi = \cos \arctan\left(\frac{MVarh}{MWh}\right). \quad (3.1)$$

where MVarh represents the reactive power flowing to the grid at any given 60-minute period, with three second average values for each data point and 95 % probability as per IEC61000-4-7. MWh values correspond to the active power measurements from the same one-hour period. When applying the grid code requirements to equation 3.1, we get

$$\cos \varphi = \cos \arctan\left(\frac{0.5}{1}\right) = 0.8944 \approx 0.9. \quad (3.2)$$

The calculated power factor is an average value recorded in 3 second intervals. Hourly 95th percentile values were calculated for the power factor, and those values are presented in **Figure 9**. Merus® STATCOM was able to hold the power factor above the set limits.

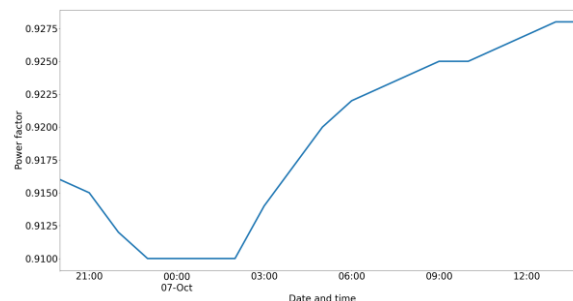


Figure 9 Hourly 95th percentile values of the power factor measured at the point of common coupling.

3.2 Voltage variation

As described previously, the reactive power flow to the furnaces changes rapidly between different phases of the melting process. As the furnace consumes more reactive power, it will also reduce the voltage in the medium voltage bus. This leads to large voltage variations in the medium voltage bus presented in **Figure 10**.

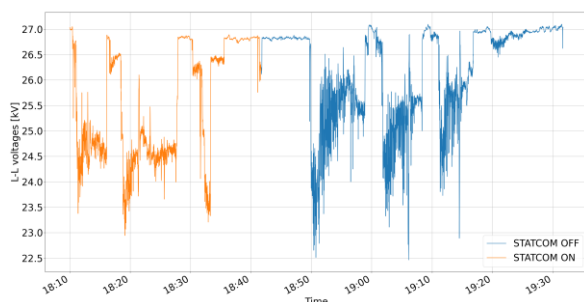


Figure 10 Medium voltage bus line-to-line voltage variation with and without Merus® STATCOM in operation. Voltages drawn in orange are when STATCOM is in operation.

When the Merus® STATCOM is enabled, the voltage variations are reduced compared to the situation when the furnace is being operated without the STATCOM. Voltage variation is related to multiple power quality problems, such as flicker and reduced productivity of the furnaces. These can be improved substantially by using a Merus® STATCOM.

The voltage variation noticeably decreases when the STATCOM is operational, as illustrated in **Figure 10**. Specifically, the standard deviation of the line-to-line voltage drops from 0.74 kV to 0.47 kV when the STATCOM is in operation.

3.3 Increased productivity

EAFs have the characteristics of constant impedances, and the power of a constant impedance is proportional to the square of the voltage as shown:

$$P = P_0 * \frac{U^2}{U_0^2} \quad (3.3)$$

Where P represents the active power of the furnace at voltage U . P_0 and U_0 are the nominal active power and nominal voltage used for reference. For example, when the voltage increases from the nominal by 10 %, the active power increases by 21 %.

As discussed in the previous section, the voltage variation in the medium voltage bus decreased when the Merus®

STATCOM was turned on. Since furnaces electrically act as constant impedances, the voltage variation causes similar variations in the powers flowing to the furnace.

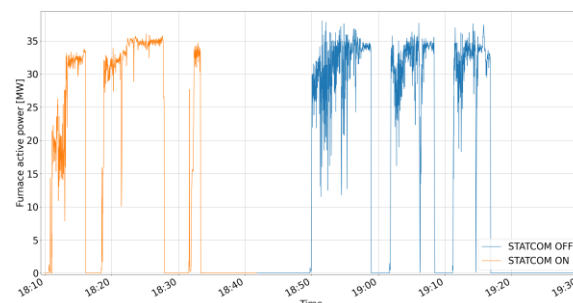


Figure 11 Furnace active power measurements taken concurrently with the data in **Figure 10**, showing similar variations in power. Powers indicated in orange correspond to when the STATCOM is in operation.

Furthermore, when the voltage fluctuation is smaller in the medium voltage bus, the furnace will operate with a higher average active power, leading to shorter melting times, if the needed energy to melt steel remains the same. In **Figure 12**, the average active powers of the studied furnace are presented, and the measurements were performed with and without the Merus® STATCOM.

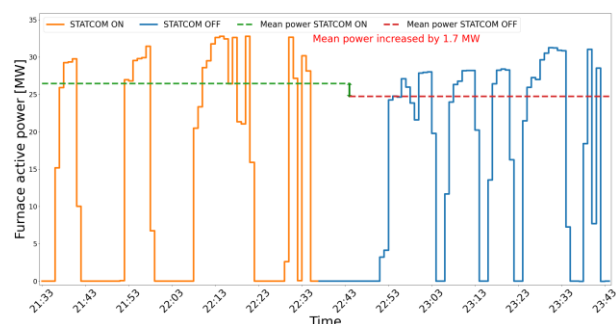


Figure 12 Furnace average active powers (1 min) with and without the Merus® STATCOM solution.

When comparing the data presented in **Figure 12**, the average power measured 1.73 MW (7 %) higher when the Merus® STATCOM was in operation when compared to the latter melt without the Merus® STATCOM.

4. Conclusion

This study presents a compelling case where the client, initially seeking to eliminate costly financial penalties associated with excess reactive power transmission, achieved this goal with significant margin following the implementation of the Merus Power STATCOM. Furthermore, owing to the STATCOM's extremely precise dynamic response, the facility experienced a notable improvement in overall operational and production key performance indicators (KPIs). The increase was mostly caused by reducing the voltage variations in the medium voltage bus by compensating for the reactive power. As

the furnaces can be thought of as constant impedances, the active power flowing to the furnace has a quadratic relation to the voltage as shown in Equation (3.3).

In **Figure 12**, 1-minute average active powers are presented with and without Merus® STATCOM. The furnace was operated with a 7 % increase in active power. This active power increase will lead to shorter melting times, leading to an increase in annual steel production. The furnace can also be operated with the same active power as previously, but then the added benefit for the process would be a reduced current, reducing the losses in the system.