FURNACE POWER SUPPLY REQUIREMENTS FOR A HIGH POWERED SMELTING FURNACE

D. Shevchenko[1], B. Anderson[2], J. Wikston[2] and L. Kadar[2].

[1] ProNico, El Estor, Izabal, Guatemala, dshevchenko@cgn.com.gt
[2] Hatch, 2800 Speakman Drive, Mississauga, Ontario, Canada, L5K 2R7 lkadar@hatch.ca

ABSTRACT

Increasingly marginal ore bodies and rising costs have put already low margins in the smelting industry under pressure. Operators have turned to greater efficiencies as a solution and in many cases larger, more intense furnaces have played a critical role is delivering greater profitability. Higher power levels and higher electrode voltages result in power supply system challenges and a greater potential for power quality implications on the supply system. In addition, power quality requirements from the power supply utilities are becoming stricter or are being more rigorously enforced. These, combined with an increase in the number of islanded power systems being used to power facilities have resulted in more complex and intricate designs being required to provide reliable integrated systems. High intensity, high power furnaces are here to stay and designers and operators must consider the electrical implications from a whole system perspective.

This paper provides an overview of some of the common challenges large furnaces can create on power supply systems, either islanded or not, as well as available design philosophies and developments in electrical equipment for the mitigation or elimination of these problems. Technologies applicable to both existing and new facilities are presented and a case study for an existing facility is presented.

1. INTRODUCTION

In the past the furnace power loads were small based on the short circuit capacity of the system (high short circuit-to-load ratio) and larger facilities were developed with multiple furnaces. Usually the values were well over 25, sometimes even exceeded 50. In these cases there were no special requirements from the utilities. However, recently even when the power supply system is considered strong the utilities may require that the power quality to be maintained in a certain range. This will require the user to install power factor compensation capacitors, harmonic filters and, sometimes flicker mitigation equipment. On weak power supply systems this equipment becomes a must. If the user is required to generate its own electricity, the user can mitigate between its investment in power quality equipment and what it is willing to tolerate on its own islanded network.

This paper will present design philosophies which one could use in developing or upgrading the power supply system as well as discusses electrical equipment to address these issues.

2. DESIGN PHILOSOPHIES

The successful operation of a smelter complex depends significantly on the robustness of the power supply system. To ensure a dependable and reliable power supply, one needs to carefully design the power supply system to address present and future requirements of both the plant and the utility.

The first step is to properly characterize the furnace load. The main characteristics are:

- Furnace type – 3 electrode circular, 6 electrode rectangular, DC, etc.
- Furnace load (MW) – present and future
- Furnace operation – resistive immersed, immersed arc, arcing. Note that these types of operation may change during the lifetime of the plant based on the power levels and/or ore composition.

Based on the operation type it is possible to approximate statistically the magnitude of power quality disturbances, such as:

- Current fluctuation (power stability)
- Current harmonics spectrum and magnitudes
- Unbalances

The second step is to identify the power supply system options:

- Grid connection
- Islanded system
- Combination of the above

This identification will be based mainly on availability of the grid power at the plant location and cost of bringing the grid power to the plant. Step two shall be able to provide the strength of the system and its reaction to load step changes. In the island mode case this step includes the design of the system, in particular the ride through characteristics of the generating system. With this information and the information identified in step one, calculations can be carried out to identify the expected magnitudes of the power quality parameters, such as voltage fluctuations, voltage unbalances, flicker and system stability.

Power generation for smelters has mostly been based on thermal power generation: such as gas turbines, steam turbines or diesel power. On occasion hydroelectric power plants have been used. Recently with the falling costs of wind turbines and solar panels, wind or solar power have become attractive solutions in locations with strong renewable power resources. Intermittent nature of wind and solar power require other dispatchable sources of electricity to be used in a hybrid combination. In these cases power quality compensation equipment may also be added to smooth the effect of renewable power fluctuations.

One should be aware that most power supply utilities will associate “arc furnace” load with a steel furnace type of load, which most likely will not be the case. Thus, one shall properly present and educate the utilities about the expected load and its actual power quality impact. This will ensure that the compensation system will be optimally designed to both parties’ satisfaction.

3. POWER QUALITY COMPENSATION EQUIPMENT

In this section we will describe shortly the most common and some new equipment which one can use to address power quality issues. One can broadly categorize this equipment in three types:

a) Series equipment which is connected in series with the furnace load, such as series reactor, thyristor systems, etc.
b) Shunt (Parallel) equipment which is connected in parallel with the furnace load, such as, SVC, filter banks, etc.
c) Controls

Below the most common equipment is presented in brief.

3.1 Series Equipment

Series equipment is intended to smooth out the current, as well as the power variation of a furnace load. Since it is connected in series with the furnace load, they will have a direct effect on the furnace operation.

3.1.1 Series Reactors[1][2]

The series reactor, see Figure 17, is either fixed or tapped, and is used to stabilize the arc in the furnace by ensuring that the current variation with time is reduced. Their size is optimized for given operational points. Sometimes saturable reactors, saturated naturally or by electric means, are used to be able to vary the reactance dynamically. However, these units can introduce significant harmonics and their use is limited.

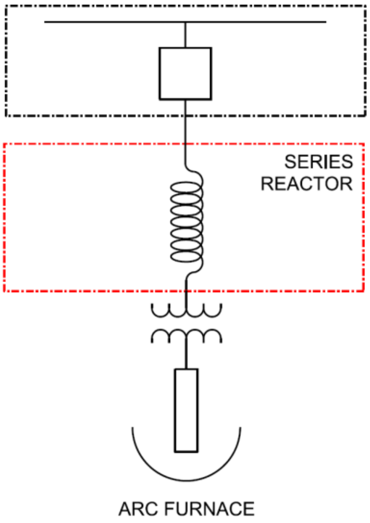


Figure 17: Series Reactor

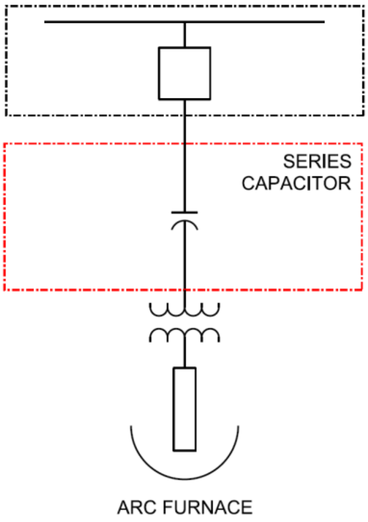


Figure 18: Series Capacitor

3.1.2 Series Capacitor [3]

Series capacitors**,** see Figure 18, are intended for power factor compensation. However, due to significant voltage increase introduced by this equipment, lately its use has been abandoned.

3.1.3 Thyristor systems

SPLC [4] and “thyristor converter” [5] are the two series connected technologies using thyristor devices. These devices have two main objectives:

- Boosting the furnace power during power dips.
- Clipping power peaks above the furnace set point.

The results are:

- Higher annual average power delivered to the furnace.
- Reduced operator intervention.
- Consistent use of balance of plant (kiln, feed transfer, cooling etc).
- Reduced electrode movement, leading to stable arc cavity.
- Plant’s possible grid connection approval by utility.

Usually, the thyristor-controlled devices will require additional shunt devices to mitigate the current harmonics and/or reactive power generated by such equipment.

The SPLC, Smart Predictive Line Controller, is located on the primary side of the furnace transformers with a reactor parallel to the thyristors, see Figure 19. The SPLC varies the series reactance to control the power demand. This is done per phase. The SPLC has a wide control range to aid in smoothing out the dips and peaks. The technology is proven for 3 electrode, 6 electrode, smelting, melting, and high power long arc operation.

The “thyristor converter” is a single phase converter located on the secondary side of the furnace transformer, see Figure 20. The converter operates by varying the electrode current and voltage to control the power demand. This is done per electrode pair in 6-electrode furnaces. The technology is proven for 6 electrode smelting operations but has yet to be proven on an industrial scale for furnaces with high power long arc operations (open or shielded). Although it should be feasible, 3-electrode furnace operation is still not implemented.

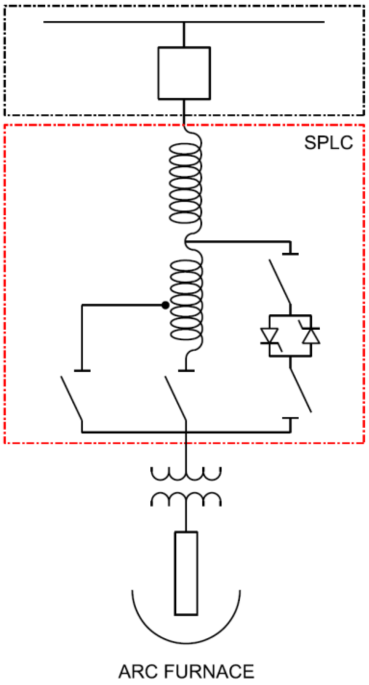


Figure 19: SPLC One-Line

3.2 Shunt (Parallel) Equipment

The shunt connection equipment is designed to maintain the desired power quality parameters at the furnace power supply bus. Since it is parallel with the furnace load, theoretically, the furnace can still be operated if the shunt equipment is taken off the circuit.

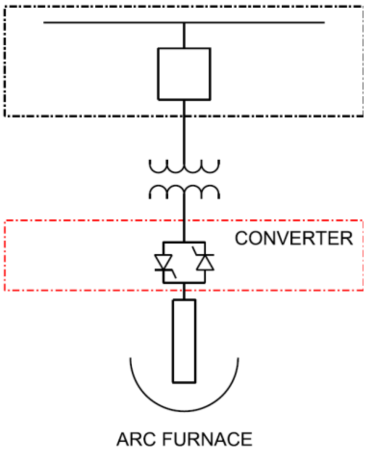


Figure 20: Converter One-Line

3.2.1 Power Factor Compensation Capacitors and Harmonic filters [6]

Such equipment consists of passive components (capacitor, reactor and resistor), see Figure 21. Due to this, they can be optimized only for a certain operating regime. If a furnace is expected to operate at few different power set points, the system can be designed with banks that, by judicious switching, can provide the optimum compensation for each operating point.

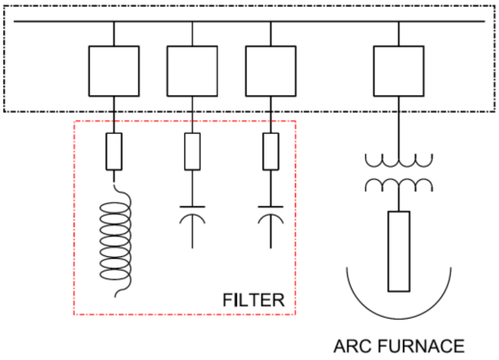


Figure 21: Filter One-Line

3.2.2 SVC [7]

Static VAr Compensator (SVC)has been commercially available since the early 1970s for furnace applications. This device provides the same function as a power factor compensation capacitors/harmonic filterswith the additional benefit of being able to continuously vary the required reactive power as is demanded by the operation. It consists of several harmonic filter/power factor compensation banks in parallel with a thyristor controlled reactor. This technology is based on thyristors which are a natural commutation device and have an open loop response time of approximately half of an electrical cycle and a close loop response time on the order typically of 2 to 3 seconds. These devices have been providing flicker reduction technology to the furnace industry for decades.

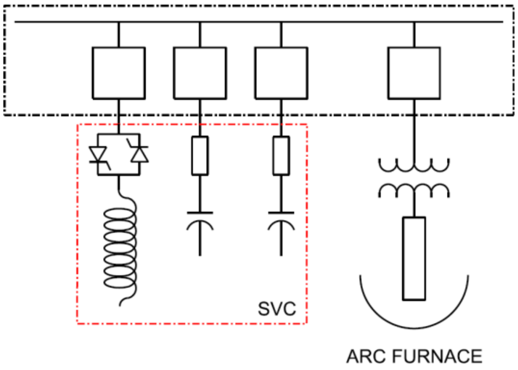


Figure 22: SVC One-Line

Figure 23: SVC at Case Study Location

3.2.3 Statcom[7]

A Static Compensator (Statcom) provides better and faster power quality parameters corrections than an SVC. It has been commercially available for over a decade under different trade names. It is more complex than an SVC and uses the IGBT (Insulated Gate Bipolar Transistor) technology. A modern multi-level convertor can provide an effective switching frequency of 12 kHz. With this effective switching frequency these devices have a very fast response time to any disturbances, in the order of a few milliseconds. Due to the multi-level design each level is switched at a low rate which results in lower switching losses and a more efficient device.

3.2.4 Energy Storage Equipment [8]

Development of energy storage technologies has advanced significantly in recent years. It is possible to use stored energy to balance and smooth fluctuating load and/or generation. For furnace applications, probably the best technology presently available is the flywheel. Several different flywheels are commercially available with a wide range of energy and power capacity allowing the rated power delivery for time spans of up to several minutes. These devices can operate with a 10 ms response time and have an unlimited number of charge/discharge cycles, therefore when operated with margin for both supply and consumption of energy they can change a rapidly fluctuating profile into a smooth and slowly varying profile. Therefore, with proper design the active power of the furnace can be smoothed out from the generation point of view which reduces wear and tear of on-site generation and grid generation. On a 120 MW six electrode furnace, a system of approximately 45 flywheels would be required. These systems can supply both active and reactive power and operate in a frequency control mode therefore during an onsite generation trip or loss of grid power the house load can be maintained for minutes while fast starting diesels (10 MW units can start and reach 100% load within 140 seconds) come on line to support the load. It is expected that this and similar technologies will be deployed on smelter plants in the near future.

3.3 Controls [9][10]

3.3.1 Furnace Power Regulation Controls

A basic furnace power controller consists of a set point regulator, usually a combination of an impedance set point and power set point. This will control the electrode positions and the furnace transformer tap.

Advanced furnace power controllers are software-based solutions that provide additional functions to improve the furnace and plant operation as follows:

- Power demand control which can be connected with the power utility demand controller.
- Reduction in frequency and duration of power dips and peaks by anticipating future furnace behaviour.
- Avoidance of furnace trips
- Coordination with the furnace feed and tapping systems
- Dynamic set-point control based on furnace mass balance, localized hot spots and energy balance
- Ability to dynamically tune and adjust the activity, speed and sensitivity of the electrodes and transformer tap actions.
- Optimize power input to extend furnace refractory campaign life.
- Customizable to the actual plant conditions and process.

3.3.2 Master Control to Match Generation and Load

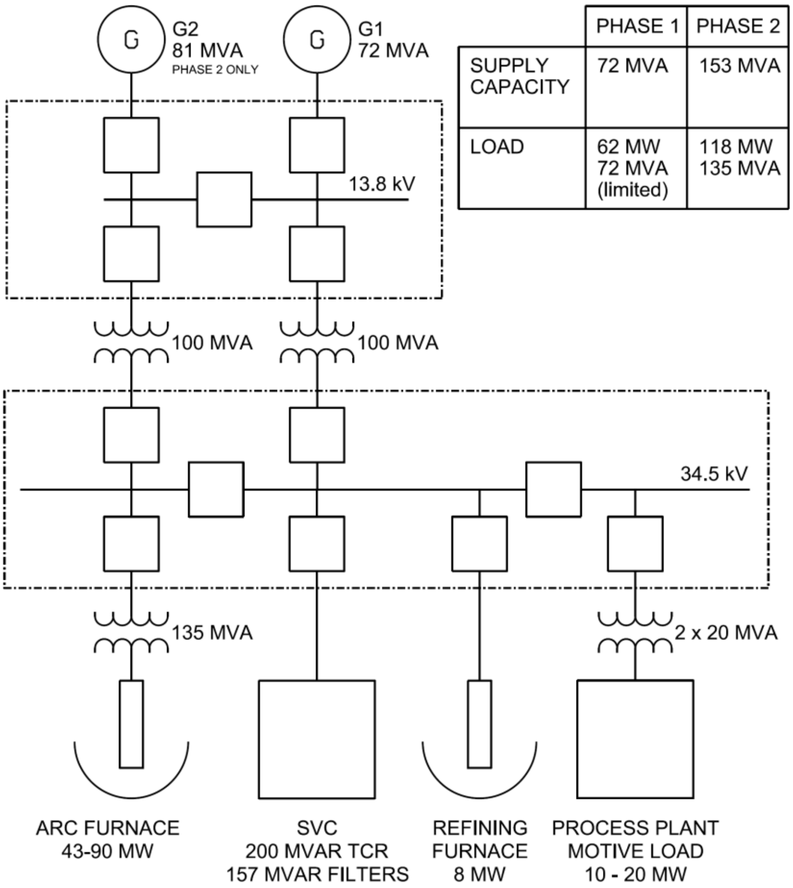
In addition to the furnace power regulation controller it is advantageous to implement a master controller. This master controller oversees the total plant, coordinating multiple furnaces and multiple generation sources. It does this by providing supervisory commands to the system equipment; this system equipment controller itself is generally not aware of events outside of its boundaries and needs this intervention by the master controller.

3.3.3 High-speed Control

Depending on the specifics of a system event, power control by electrode and tap movement could be ineffective. This is because the electrode movement and tap changer operation speed is relatively slow (seconds). High-speed controllers adjust set points on high speed power electronic equipment such as: DC Furnace rectifier, SPLC, Thyristor Converter, Energy Storage Power Supply, SVC, Statcom, etc. Such equipment has a response time in the range of 50 ms or less. The result is effective mitigation of the system event. The communication between the system devices and the master control system has to be sufficiently fast. Hardwired inputs are the obvious solution but networked technologies such as IEC 61850 also provide communication at sufficient speed.

4. Case Study – Islanded FeNi furnace

As an example of how the above mentioned devices are applied and chosen, we present the case of ProNico operating a 90 MW nameplate three-electrode round furnace in El-Estor, Guatemala. This site development was based on a smelter plant mothballed 30 years ago. The original smelter consisted of a local (islanded) generator and a 40-MW furnace. Based on the proposed new mining developments, a new furnace was required which could be operated at two-power levels. The first power level is at 40 MW, which is an immersed operation. The other power level is the nameplate value of the furnace, at 90 MW. This operation will be an arcing operation.



	PHASE 1	PHASE 2
SUPPLY CAPACITY	72 MVA	153 MVA
LOAD	62 MW 72 MVA (limited)	118 MW 135 MVA

Figure 24: Case Study - Simplified One-Line

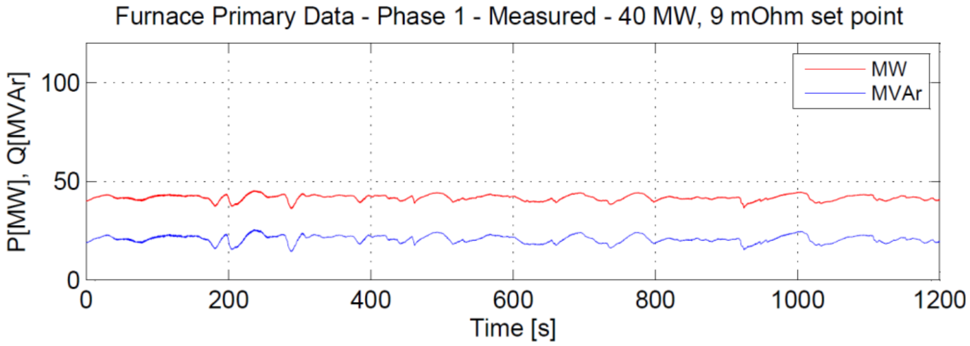


Figure 25: Case Study - Arc Furnace Load Profiles – Phase 1

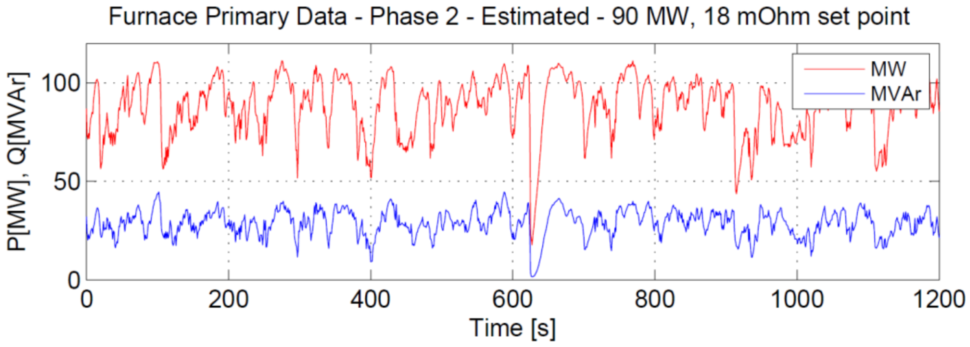


Figure 26: Case Study - Arc Furnace Load Profiles – Phase 2

Based on an overall review of available electrical energy options, grid connection at this stage was not feasible. Although the power grid has been developed in the last 30 years, its capacity for the plant use was capped to around 2.5 MW. Thus, it has been decided that the existing 72-MVA steam turbine generator will be refurbished and upgraded for the initial lower power requirements. The limited grid power will be used only for essential and emergency services. In addition, an SVC was installed. The SVC was designed for the future full plant load. However, it would operate at a reduced capacity at the beginning and will help to maximize the active power output from the generator (see Figure 24). A second generator was to be commissioned later, after furnace start-up, so the entire plant power can be provided. In addition, allowance was made for the future installation of a series reactor or SPLC, if required.

4.1 Furnace Load Profile

Figure 25 and Figure 26 show the load profiles for the furnace at two power set points. At 40 MW immersed operation the power is very smooth. At 90 MW shielded arcing operation the power levels vary quickly and considerably. The fluctuation is due to the inherent variation in the electric arc's impedance. Power swings of +20% and -50% are common.

Arc-stability can be an issue in arcing furnaces. Systems with low reactance and long arcs can be inherently susceptible to loss of arc. These losses of arc lead to very rapid changes in the power demand, typically the power demand in a 3-electrode furnace will dip by 50% in several milliseconds. At Pronico, during furnace operation at 40 MW in arcing mode, the measurements of the electrode current showed that no loss of arc occurred, as predicted by the model.

4.2 Stage One Power Limit

The first challenge in an islanded system is power capacity. In our case study the generator limit of 72 MVA limited the arc furnace to an average of 40 MW in order to operate the balance of plant simultaneously. In order to maximize the active power delivered to the load it was necessary to use reactive power compensation at this stage. The SVC allowed the generator to operate at its rated active power without exceeding the rated current. In the absence of the SVC the arc furnace was limited to approximately 30 MW.

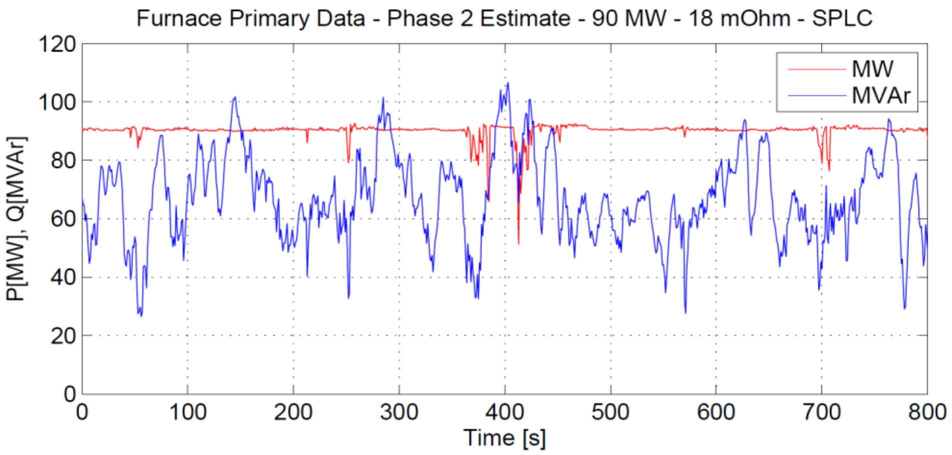
During stage one the generator was generally run at its rated capacity. The arc furnace occasionally dipped power by approximately 40% within a few seconds. These dips were due to feed cave-ins inside the furnace. These power dips were a source of generator trips; the generator would trip on under-frequency during the power ramp up after the power dip. The challenge was to decrease the rate of power ramp-up in the furnace and to increase the power ramp-up capacity of the generator. The generator and furnace controllers were tuned to solve this issue.

4.3 Local effects of Power Quality

The low fault level on the 34.5 kV bus did lead to some power quality issues. During energizing of the furnace transformers several of the more sensitive devices in the motive plant system failed, mostly variable speed drives. The failures were due to voltage transients. Similar issues occur during loss of furnace load, where 50% of furnace load rejections lead to drives tripping in the motive plant. In order to mitigate against this problem the point of common coupling is set at the 13.8 kV bus. This is an ongoing matter at ProNico with generator co-ordination and tuning under development

4.4 Active Power Smoothing

As the power is gradually ramped up to 90 MW the power instability will increase. Co-ordination of the two generators and the unstable furnace load is the main challenge. This operation is still ongoing; depending on the results of the co-ordination it may be necessary to implement an active power smoothing system. Refer to Figure 27 for an example load profile where the active power has been smoothed by using an SPLC. With similar compensation at ProNico it will be possible to maintain an average furnace power near the rating of the generation system. It should be noted that the SVC will suitably compensate the reactive power demand such that the generation system does not have to provide the reactive power shown in Figure 27. In addition it may be required to install a master power controller to coordinate the two generators and the furnace loads.



Estimated Load Profile with Active Power Compensation

5. CONCLUSIONS

As presented in this paper, the selection of the power supply system for a furnace load is a complex procedure which has to take into account the available energy options, power quality requirements and furnace and plant load profiles – present and future. On this basis, one can choose from several electrical equipment options and develop an optimized system for the particular plant. However, this shall be a well thought out and an in depth process to ensure that the power supply is optimized for present and future plant demands.

The paper also highlights that proper design of the system is essential to avoid future costly equipment upgrades for an ever evolving plant operation. Thus, the long-term plan of the operation shall be considered in a design.

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