

The only future for glass industry will be “all-electric”

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Abstract

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Human beings are melting glass for almost 5000 years and for most of that period that has been done by using wood as a heat source. Around 1850 we start using fossil fuels and it looks like humanity will manage to use it all up before 2200. Although we still have some generations to go before that will happen it seems that we are coming close to the point where renewable energies are becoming cheaper than fossil fuel energy. Last year we already witnessed that happening in parts of Europe already. Next to the environmental advantages of using renewable energy there are even more advantages to all-electric melting.

This lecture will try to cover the today's technology of innovative power supply systems that we made available to the furnace designers. Today's electrical furnace boosting power supplies need to be energy efficient, highly flexible, real-time controllable, process intelligent, molybdenum and tin-oxide friendly, achievable and standardizable. Old fashioned oil filled stepped and variable transformers don't meet these requirements anymore and therefore we have designed solid state based power supplies that meet the requirements of new all-electric furnace designs. The lecture will cover efficient phase angle and well as load managed burst firing techniques in single, dual as well as in three phase configurations next to cathodic protection and flexibility capabilities. It intends to stimulate glass manufacturers to re-think their today's melting technology and start to consider “all-electric” melting in near future.

Keywords:

Renewable energies
Emission legislation
Capex against or with Opex?
Utilities, energy suppliers and industry: how flexible can it be?
Electric furnace boosting
Power factor improvements
Efficiency improvements

About the Author:

René studied electrical engineering and has been with the Schneider Electric group for 8 years. He started his career in the paper industry as a technical assistant, before switching to the glass industry as an employee of Vereenigde Glasfabrieken. During his early years, he built his broad knowledge and experience in design and development of electronic quality equipment for container glass manufacturing

and was involved in the implementation of their first generation PLC and DCS systems, as well as electronic timing systems for IS-machines.

René produced several model based predictive control (MPC) projects, as well as being involved in object oriented engineering method developments. He became responsible for process control inside the BSN group and finally was responsible for the European plant process control and forming electronics inside the Owens-Illinois group.

Today René is Eurotherm by Schneider Electric's global glass business technical manager, focusing on process and power control solutions, energy management and MPC for end-users, OEM's and solution providers.

His motto is: "If you wait, all that happens is that you get older". Be conservative during the campaign but be extremely innovative during builds and re-builds.

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Introduction

There are physical limitations to the ongoing commercial strive for higher glass furnace pull rates. One of those constraints is the maximum temperature that the crown refractory has to withstand, which has a direct correlation with the amount of energy that can be applied by combustion of fuel. To enable the input of more energy, without the side effects of higher refractory superstructure temperatures, there is method known as electrical boosting. Not only is boosting capable of applying potential amounts of energy to the melt, it is also capable of providing better control of glass melt flow currents and stirring effects, resulting in more efficient fining processes (especially in the case of barrier boosting). Electrical boosting is in principal a very efficient method of energy transfer as long as the system that provides the electrical power is built in line with the latest technical standards.

This paper will describe how multi zone boosting systems can provide optimum power control and power distribution by controlling the power to each pair of electrodes separately. It will also illustrate how to avoid typical glass melt "hot spots" by controlling multiple electrodes in one zone.

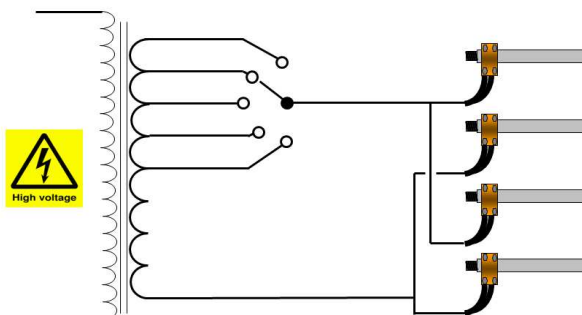
Different methods of controlling power with semiconductors (thyristors) will be explained along with how possible negative side effects, like reactive power, peak power demand and harmonic distortion can be solved through smart methods of control.

It will also describe how different boosting system designs, using higher intermediary voltages and super-compact water-cooled transformers contribute to:

- Reduced energy waste
- Greater electrical power efficiency
- Power factor improvements
- System standardisation
- Cost-effective system design
- Optimised stable glass melt flow patterns

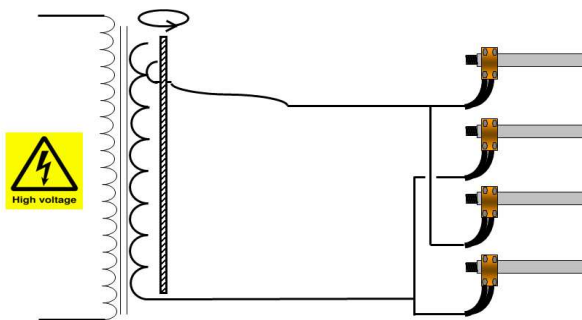
Multiple taps transformer design

There are many ways of controlling the electrical power in a furnace boosting system. Before high power variable transformers became available, multiple tapped transformers were used. With those transformers, the power could only be controlled in several fixed and predefined steps and in many of these applications the transformers primary high voltage had to be switched off before the secondary taps could be switched. This resulted to unwanted high voltage switchgear wear that eventually led to boosting interruptions due to the necessary manual switch gear maintenance. Negative power control effects caused by incoming power fluctuations are difficult to control in such systems and can have a direct and relatively quick uncontrollable effect on glass temperatures.



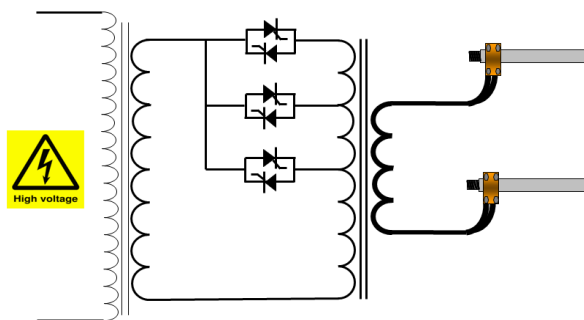
On-load stepless transformer design

Most often today, high power variable transformers are installed. The main advantage of these transformers is that they are capable of applying continuous controlled power to the boosting electrodes. They are capable of controlling incoming power line fluctuations and are easily adapted to modern furnace control strategies. The main disadvantage is that the slide-wires are subject to wear, especially in those applications where they are used to control fluctuations on the incoming line, or where the boosting system is used to control the glass temperature. Repairs of mechanical parts in such transformers are expensive and time consuming. Because they are normally oil-filled, they also have to be placed in a specially equipped room which in most cases is too close to the furnace. Consequently, this type of a boosting system design will need to have long and expensive electrode wiring or bus bars that introduce unwanted resistive and inductive power losses. We also need to take into account that modern variable transformers often have oil/water heat exchangers and should be considered as water-cooled boosting systems.



Multi tap transformer with automatic tap changer

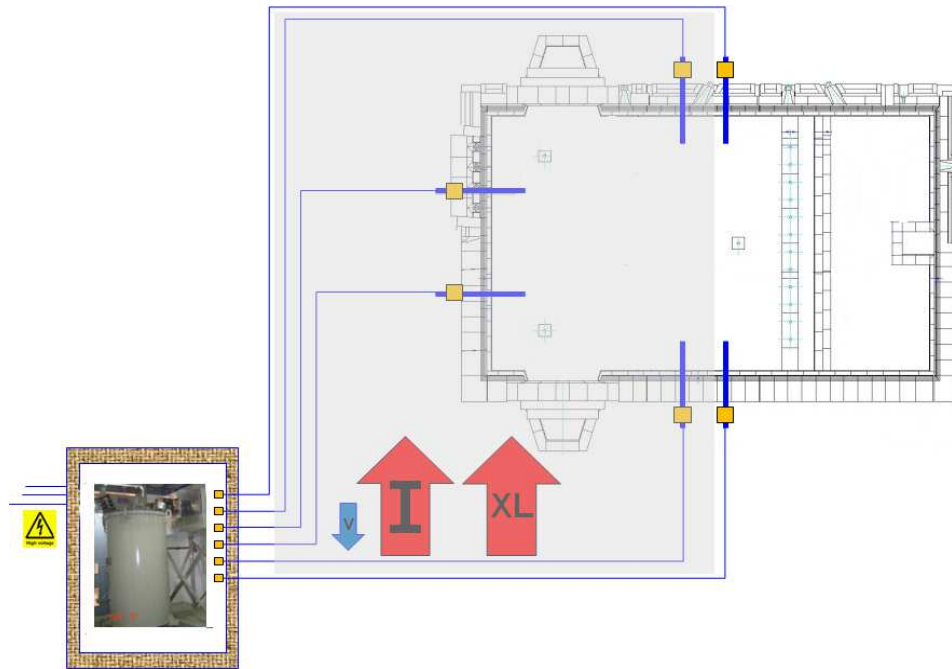
High power SCR (Silicon Controlled Rectifier) systems became available at a similar time to variable transformers, and they also found their way into furnace boosting control systems. The main advantages of SCR controlled systems are that they are based on solid state technology and will therefore not suffer from wear, are continuously controllable and are capable of very precise power, voltage or current control. The thyristor (high power semiconductor switch) part of these controllers has not changed much over the years, however, the latest digital microelectronics have taken over the control, providing multiple new control methods that enable overall system efficiency improvements and increased precision.



Traditional on-load stepless transformer boosting power supply designs

Because stepless transformers are oil filled, they have to be located away from the furnace itself in a specially designed and approved building. The distance between the transformer and the furnace can therefore be relatively long. A stepless transformer converts incoming high line voltage directly down to the boosting electrode at a maximum of 200VAC (container glass applications). In order to apply sufficient power to the furnace the current running in between the electrodes and the transformers is relatively high. According to Ohm's law and

assuming that an average of 400kVA is applied to a single boosting zone, the current running through the transformer, cabling/busbar and electrodes will be 2000A. Cabling/busbar losses will be $P=I^2R$, so twice the current will result in quadruple the cable/busbar losses and vice versa, thus $\frac{1}{2}$ current equals $\frac{1}{4}$ power losses over the cabling/busbar. Another negative side effect is that it is hard to achieve the optimum cable/busbar pathway in order to keep loop inductance as low as possible, because the transformer location as well as the electrode positions is fixed. Either the cable/busbar design becomes very complicated and expensive, or the design is simple and cheap, but either way potential energy losses over the whole furnace campaign are taken for granted.

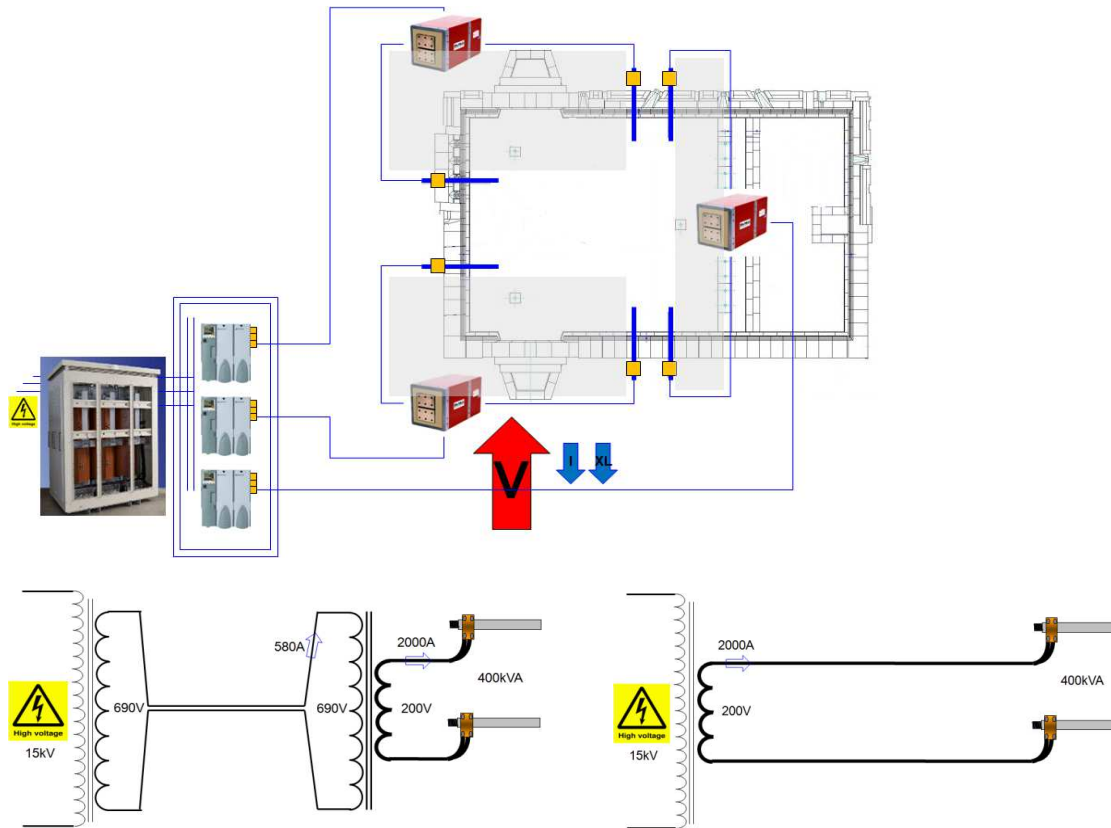


Dual transformer with SCR control

From the single stepless transformer design, we learned that such a boosting system's efficiency suffers from running high currents at relatively low voltages. Even an expensive and improved cable/busbar design will cause relatively high inductances leading to unwanted generation of reactive power. This reactive power has to be considered as power loss as it is not contributing to the energy the system is capable of adding to the glass melt. Nevertheless, you are often charged for real as well as reactive power by your electricity supplier. The reactive power of the system will account for a higher total power charge and a higher peak demand charge in the system. Because the system has to account for a higher secondary voltage on the transformer with the large bus work, the turns ratio (secondary voltage = primary voltage/turns ratio) will be lower causing more primary current at a lower power factor to be used in the application. Of course the incoming high line voltage and the maximum electrode voltage cannot be changed. The solution is to run the boosting control system at the highest possible voltage, then lower it to the desired boosting electrode voltage as close as possible to the electrodes. In other words, avoid high currents running through cabling/busbars for as long as possible. This can only be achieved by using a two transformer design and by putting the second transformer as close as possible to the boosting electrodes.

To achieve this you first need to step down the voltage to the SCR. Eurotherm recommend the use of an air-cooled line-step-down transformer to reduce the incoming line voltage down to 500V. (We use +/-500V as the intermediary voltage because of the physical properties of a transformer to transform the voltage applied to a specific tap up to a higher voltage level appearing on a higher tap). We also advise 690VAC as maximum intermediary voltage due to the fact that this is still considered to be low voltage, and therefore no special measures or specially trained maintenance personnel are required. Eurotherm SCR controllers are designed to

control up to 690VAC, and they are used to supply the high power at 500V to water cooled transformers located as close as possible to the boosting electrodes, where the voltage is transformed down to the desired electrode voltage of 200V. Thus, the long distance running current is reduced by 2.5 times and cable losses by 6.25 times.

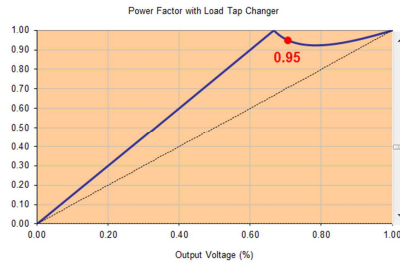
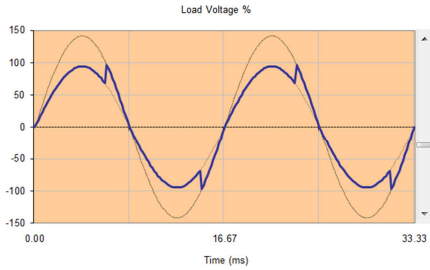
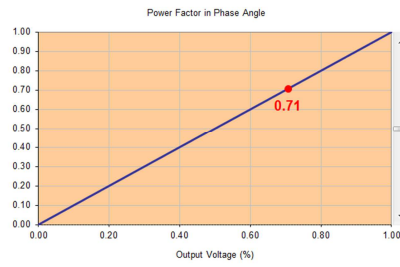
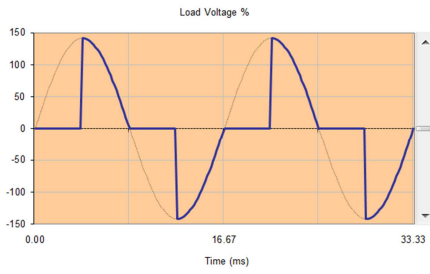


Traditional SCR control vs Load Tap Changer

The traditional method used to supply power from an SCR to resistive loads such as glass heating electrodes is phase angle firing, but this method causes harmonic distortion on the cables that typically degrades the power factor. The power factor decreases rapidly as output power is increased, for example in a typical installation at 50% power, the power factor can be around 0.7. At 25% power, the power factor can decrease to around 0.5. Moreover, phase angle firing creates all sorts of disturbances on the electrical grid, such as harmonics, RFI (Radio Frequency Interference), power line losses, wasted energy (reactive power or kVAr) and overheating of the transformer. The end-user will eventually be forced to increase the capacity of their equipment to compensate for these disturbances, for example by installing active or passive systems such as costly capacitors.

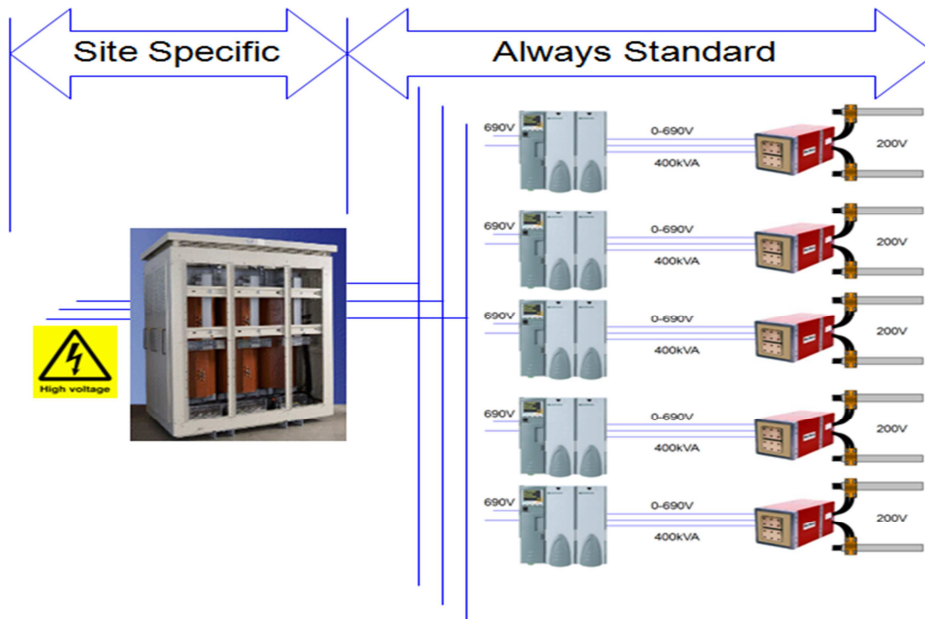
Improved SCR control

To overcome these issues and be able to profit from the advantage of a solid state two transformer boosting system design, Eurotherm introduced load tap changing (LTC). This provides an effective way of increasing the power factor of an SCR driven power system by switching in transformer taps automatically in either phase angle or burst firing modes of operation. By adding several taps to the transformer with a dedicated SCR for each tap as well as overlapping firing orders, such a system is capable of running at an increased power factor over a much larger control range when using phase angle firing. The waveforms below show the same output power ratings. In a typical example, the single SCR system is running at a power factor of 0.71 at 50% of range, while the load tap changing system is achieving a power factor of 0.95. Harmonic distortion is also reduced with LTC which results in less reactive power and therefore improved efficiency.



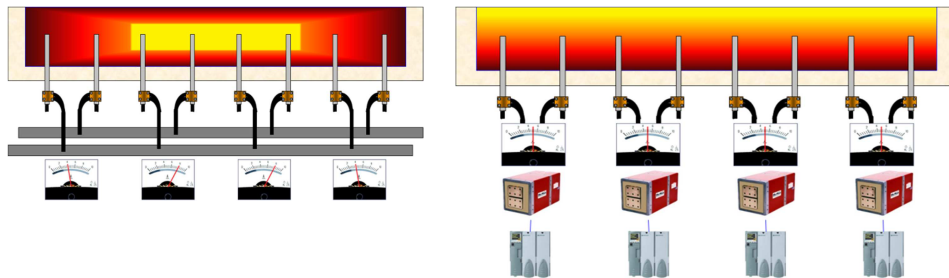
Multi Zone design

In an SCR controlled dual transformer boosting system design, it is best to use as many relatively small sub systems as possible. In fact, Eurotherm advise the use of separate sub systems for each pair of electrodes which are typically capable of supplying 300-400kVA to the furnace. The power applied to a boosting zone is normally limited by the maximum electrode current and in order to prevent excessive wear should not exceed $1.5 - 2A/cm^2$. A 5cm electrode being 70cm submerged into the glass melt will have a surface area of $1115cm^2$ and therefore should not run above $\pm 2000A$. At 200V that results in $\pm 400kVA$. These sub systems can be fully standardised and will always (and at every site) use the same intermediary voltage supplied by the high voltage step down transformer that adapts the whole boosting system to the incoming line voltage. Boosting zone voltage adaptation and LTC tap tuning will be covered by multiple primary taps at the boosting transformer. Such a standard system layout will decrease engineering efforts, spare parts and overall system cost.



Controlling power to the boosting electrodes

In respect to multiple boosting electrode zones, running controllable power on each pair of electrodes makes the whole boosting system more flexible and avoids hot spots, especially in so called barrier boosting zones, in which multiple electrodes are lined up to improve fining by energizing the glass flow loops. Hot spots may occur when all the electrodes are supplied by one phase, zone and/or busbar. The electrodes located in the hottest part of the zone will automatically have the lowest resistance and therefore introduce more power compared to those running in a colder part of the zone. That extra power increases the temperature in the part of the zone which is already running at a higher temperature and therefore the whole barrier boosting system becomes difficult to control. Multiple, smaller power systems controlling only two electrodes are easier to control and are capable of applying most of the power to the part of the zone which is the coldest.



Smaller transformers

Water cooled transformers bring several advantages to the system. The ambient temperature rating for the transformer is the incoming water temperature (typically 30°C), allowing the transformers to be located closer to the furnace than an air cooled unit. This contributes to the Eurotherm preferred two transformer design method (placed close to the electrodes). Water flow rates are low (1 to 6 GPM (Gallons Per Minute) for a single-phase unit) with a small pressure drop that can usually be put in series with other components in the existing water system. Typically, the water-cooled transformer is going to be significantly smaller than a similarly rated air-cooled transformer, allowing for placement in areas unavailable to air cooled units. They are also fully sealed with an epoxy resin so they can be sited in areas that have high dust contents and they are protected from loose debris being inadvertently dropped into the windings. Water-cooled construction does not have to allow for air gaps in the system for cooling which means less inductive reactance in the transformer.

Conclusion

Multiple zone, SCR controlled boosting systems have many advantages:

- Standard line step down transformer, no need for oil cooled transformers
- Standardised boosting zone transformers for easier purchasing and maintenance across multiple plants
- SCR power controllers can be standardised regardless of incoming line voltage
- Reduced cabling/busbar costs
- Higher electrical efficiency due to high voltages and low currents
- Lower energy bills as a result of higher power factor
- Avoid hot spots through improved temperature control, resulting in improved throughput and better quality end products
- Low maintenance due to no moving parts or wear
- In the unlikely event of failure, only part of the boosting system and only part of the total boosting power will be lost
- System designed to last for more than one furnace campaign