Making bushing control 'green'

René Meuleman, Stanley Rutkowski and Martin Moeginger consider how to improve the efficiency and profitability of bushing positions by smart design of the entire system, from the incoming power to the precious metal.

Continuous fibre glass became commercially viable after electrically controlled fibre glass bushings became available. Over the years, these bushings became bigger and bigger, requiring higher amounts of power, as well as more precise temperature control.

Today, modern glass fibre bushings require up to 90kW of power. Due to their relatively low resistance, they need to operate at around 8V and at currents up to 10,000 amps. These high currents can only be supplied by specially designed transformers and intermediary high current busbar systems.

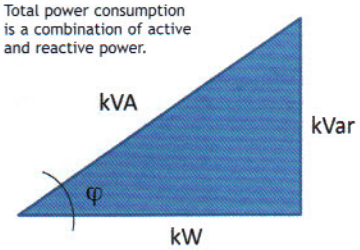
Since Ohm's and Maxwell's laws become very dominant in high current environments, bushing, transformer, busbar and power controllers need to be well designed and matched to each other in order to obtain the best possible loop impedance (resistance and reactance). The electrical efficiency differences between a normal design bushing position and an optimised position can reach up to 30%. This presentation explains how bushing loop impedance can be improved, how specially designed bushing transformers will lower resistive losses and how sophisticated 'load tap changing' power controls lower reactive power (cos φ) and improves overall efficiency. It will be shown how a carefully designed overall bushing system will improve fibre quality, reduce fibre breakage and extend bushing lifetime.

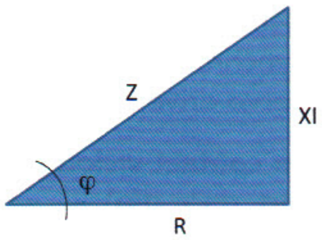
UAS, which specialises in bushing control, recently started using a modern generation of controllers that, together with highly sophisticated control strategies, provide high performance control with cost-effective redundancy options in a versatile modular system. Special control strategies and a sophisticated HMI system improve handling and help increase production quality.

Using touch panels for local control in combination with modern SCADA applications and an integrated database provides maximum availability for the operator. During the Invensys-Eurotherm development of EPower, its latest released SCR-controller (silicon controlled rectifier) has focused mainly on the glass and heat treatment industries' demands. It was obvious that a versatile, free programmable system had to be developed that also gives the freedom to adapt to many specific applications, some of which did not transpire until after the design phase. Now that EPower is installed at many customers, innovative methods of control have been discussed that became available due to the openness of an EPower system. One of them is called 'load tap changing', as described in previous editions of *Glass Worldwide* in relation to furnace boosting systems.

RoMan Mfg, an innovative transformer supplier, focuses on fibre glass bushing transformers and related busbar and cabling designs, as well as boosting and melting transformers for these applications. The company's high performing, high power and relatively small water-cooled transformers can be placed much closer to the bushing than regular transformers. Their small size and insensitivity to the heat of the bushing made it possible to design highly efficient, low inductance high current busbar systems.

Total power consumption is a combination of active and reactive power.





CONTROL PRINCIPLE

A reinforcement bushing control heating system is basically very simple, hence very difficult to control. The actual bushing is a rectangular-shaped platinum box, with thousands of nozzles and mounted in the bottom of a fibre glass feeder. Glass flows through multiple nozzles, sometimes cooled by the fin coolers and coated with special sizers forming the glass fibre yarn.

In order to control the glass temperature, in fact the glass viscosity and fiberisation process, the bushing

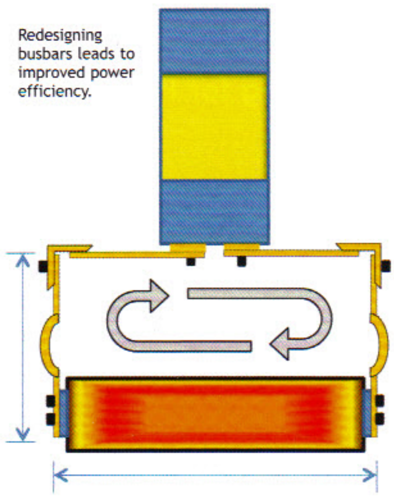
(1) Bushing	Load Current (A)	Power (KW)	Power Factor PF	Apparent Power S (KVA)	Reactive Power Q (KVAr)
Single Phase	91.08	26.86	0.65	41.54	31.69
Load Tap Changer	77.75	26.23	0.74	35.45	23.84
Difference	-15%	-2%	+15%	-15%	-25%

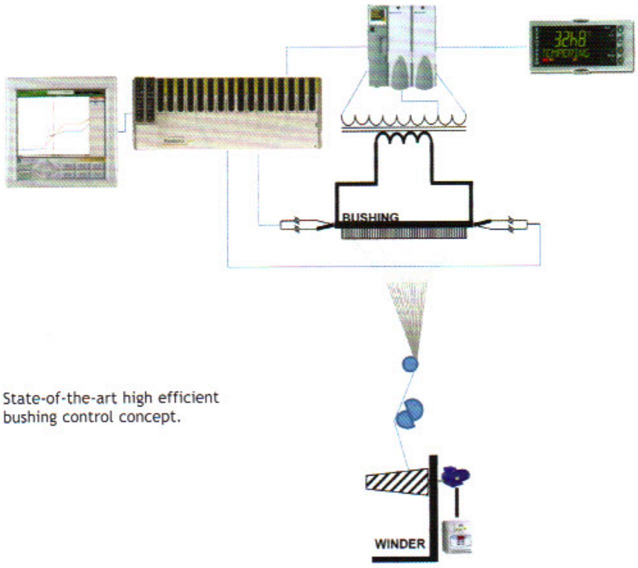
80 positions

(80) Bushings	Load Current	Power (KW)	Power Factor PF	Apparent Power S (KVA)	Reactive Power Q (KVAr)
Single Phase	7286	2,149	0.65	3,323	2,535
Load Tap Changer	6219	2,098	0.74	2,836	1,907
Difference	(1,066)	(50)	+15%	(488)	(629)

Major efficiency improvements are relatively easy to achieve.

Redesigning busbars leads to improved power efficiency.





State-of-the-art high efficient bushing control concept.

is electrically heated by running several thousands of amps through it. Since the resistance of a bushing system is relatively low, it only takes several volts to run relatively high currents and therefore the bushing is controlled by a so-called bushing transformer, transforming the incoming voltage (380Vac – 690Vac) down to approximately 4-6V. Due to a high secondary current and in order to keep power losses as low as possible, the bushing transformers need to sit as close as possible to the bushing.

Specially designed, mostly water-cooled transformers became standard in the industry. Although these transformers are positioned as close as possible to the bushing, there are still major power losses at the secondary part of such a system. In order to minimise inductive and resistive losses, special busbar designs, connections, flexibles and bushing designs are needed. The end users, together with a specialised transformer, put a lot of effort into this part of the system.

POWER FACTOR IMPROVEMENTS

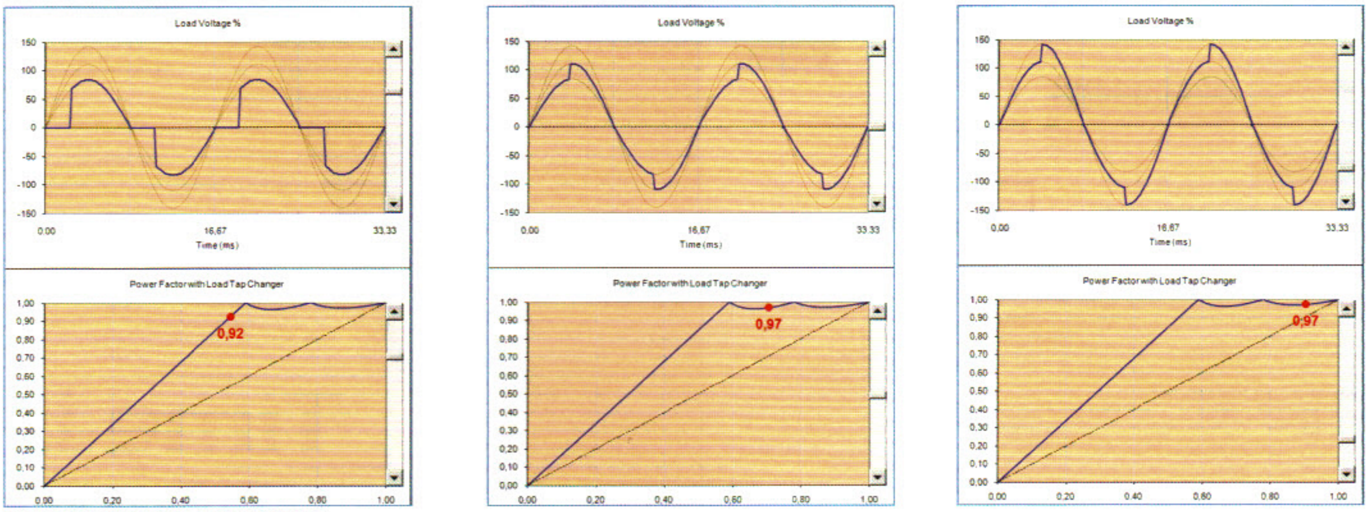
There are several methods to improve the power factor. One of the most common found at fibre glass manufacturing sites are shunt capacitor banks (SCB). In principle, SCBs compensate for the system's inductivity by adding capacity and thereby relieving the utility from the burden of carrying extra kVARs. Only those parts of the utility systems that are located before such an SCB will profit, so they need to be installed as close as possible to the reactive load.

The main disadvantages of SCBs are that they represent an extra investment (not much, although they do consume power), they require additional space and they require some maintenance. Overall, shunt capacitors only compensates for the inductive phenomena coming from the overall electrical system design and control. They fight against the damage already done.

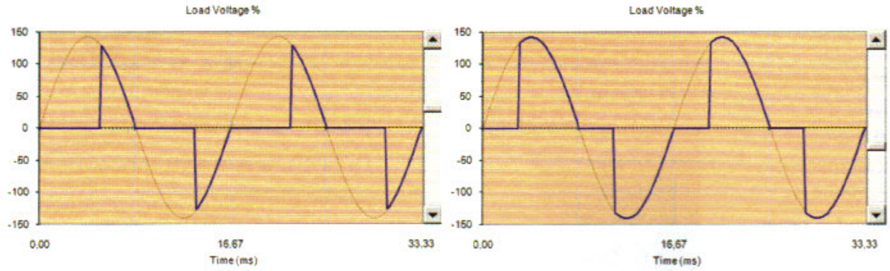
TRANSFORMER/BUSBAR DESIGN IMPROVEMENTS

Looking first at the entire secondary circuit, the connection of the power to the bushing from the transformer is both a mechanical and an electrical solution. In most applications, there are other components that need to be assessed for interferences to the connection of the transformer to the load.

In the past, mechanical considerations outweighed electrical considerations, as electrical energy was not a major cost factor in the operation of a plant. Today the cost of energy is a major concern. The electrical loss in the secondary circuit is both resistive (R) and reactive (XL). The natural power factor of the system is calculated by dividing the resistance (R) by the impedance (Z). With the combination of a closely coupled water- >



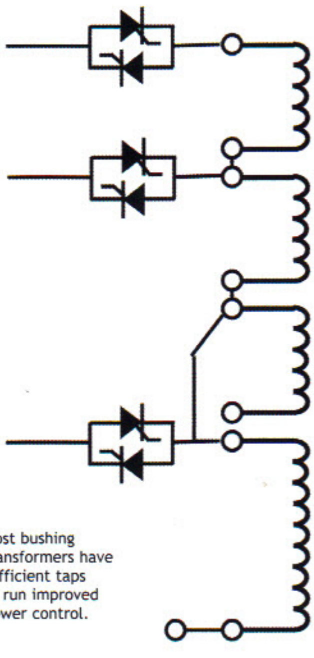
Improved power factor by load tap changing.



Poor power factor of single phase angle control.

cooled transformer and redesigning the secondary busbars, it is possible to reduce the reactive (XL) losses in the system.

The amount of reactive power (KVAR) is proportional to the amount of reactance (XL) in the system. With this reduction, the total power (KVA) is reduced in the application. The power factor is also increased by the application similarly with the reduction of reactance.



Most bushing transformers have sufficient taps to run improved power control.

PHASE ANGLE FIRING

Once thyristor controls became commercially available, they immediately replaced all other methods of bushings power control. Now, 99% of bushings are controlled by SCR (silicon controlled rectifiers) or thyristor controllers, carrying the heritage of earlier times, controlling these bushings in so-called phase angle firing mode.

In phase angle firing mode, the thyristor gate trigger pulse is controlled in respect to the zero crossing of the sinus wave; the earlier the pulse is applied, the sooner the thryristor switches into conduction and the more power is supplied to the load. In fact, phase angle firing is a very smooth method of control and has an almost infinitive setpoint resolution. However, phased angle control of thyristors has some significant drawbacks; a low power factor (cos φ) and severe generation of harmonic distortion along almost the entire setpoint range (SP 0% – 80%). To achieve an acceptable power factor, such a thyristor controller would need to run a setpoint above 80%, which can be achieved by choosing the best matching tap on the bushing transformer. In other words, keep in mind that an average bushing application would require at least +10% and -10% freedom of control next to some headroom, in order to be able to adjust the bushing temperature quickly after an incident.

All these requirements normally result in running a bushing at approximate 70%, maximum 80% of phase angle by choosing a transformer tap that comes close to these settings. Unfortunately, tap changing is not always an easy job to perform, especially 'on-the-fly'. It requires at the very least a dedicated service engineer to take charge of bushing control tap switching and needs ongoing attention and maintenance to run such a system at an acceptable power factor level. Most bushing control systems are not run under these conditions and many applications have been found running under severe conditions.

In most fibre glass production facilities, the power control cabinets are not located close to the bushing transformers and cable losses need to be taken into account. As long as such systems run a cos φ of 1, thus current and tension are 100% in phase, there is of course an unavoidable power loss of $P=I^2 \times R$. As soon a cos φ (power factor) becomes worse, the current will have to increase in order to apply the same energy to the bushing. In these situations and due to the fact that current is squared in the equation, the system will exponentially draw more power to achieve the same heating effect on the bushing.

Energy suppliers care about reactive power because even though the current associated with it does not work at the load, it heats the wires and is wasted energy. Therefore, they penalise the customers for a bad power factor or simply count those losses into the customer's kWh fees. Either way, the total amount of energy needs to be generated and each watt has a price tag on it. It makes sense to establish how energy suppliers charge for power factor to avoid penalties or discuss price discounts related to power factor improvements. Are you charged by the amount of kWhs or kVAs? In other words, reduce your power bill by improving your power factor.

Consequently, it is necessary to improve the performance of the power control system by improving the power factor by SCR enhanced load tap changing (LTC). This method became available after the development of EPower, a microprocessor and digital signal processor enhanced controller, capable of managing multiple SCR stacks in a single unit. EPower is capable of manipulating multiple stacks attached to multiple taps of a transformer dynamically. Instead of laborious manual tap changes, the device takes care of tap changing and calculates dynamically and continuously which tap arrangement best fits the actual situation.

PERFORMANCE IMPROVEMENTS

Modern control systems should bring some basic features like a clear structure, greater flexibility and maximum reliability to the operator. Invensys PAC Controllers (like T2750) fit exactly to these requirements and so build the base for the Invensys-RoMan-UAS bushing control system.

The PAC brings a clear control structure, fitted to the needs of bushing control like ramps for automatic heat-up and for the control of the temperature profile during production. In addition to the precise PID control strategy, the PAC allows a resolution better than 1°C.

The UAS bushing solution includes several features, including a controlled restart after an emergency switch off and basic operation for production data collection. The HMI is split in two parts. In the latest version, the Invensys system platform builds the main control system with an integrated database for an ideal overview of the process and production data. This system also allows the operator to handle all necessary control operation. The database provides production and process data, so the operator is able to figure out the most efficient way to control the production line.

Producing the best quality with maximum energy savings improves the process and will increase plant efficiency. For on-site control, UAS uses 17in touch screen panels for every PAC, which serves four bushings and presents the information and control features in a clear way.

CONCLUSIONS

Extensive tests have confirmed that huge fibre glass bushing energy efficiency improvements can be achieved with a better design of the transformer, busbars, power control method and improved temperature control strategies. Tests also showed that a better design of the whole system will result in less fibre breakage, longer bushing lifetimes and better fibre quality overall. By applying Ohm's law, Maxwell's laws and knowledge of the bushing control strategies, together with specially designed equipment for bushing control, UAS, RoMan and Invensys-Eurotherm can achieve 5%-35% energy efficiency improvements. Overall bushing performance improvements profits equally; just like a well-tuned engine that uses less petrol, drives more smoothly and lasts longer. ■

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