Dynamic energy management for increased energy efficiency in modern induction heating systems

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In response to increasing input costs, proactive induction heating system operators are demanding better productivity and energy efficiency from their production lines. Although already highly efficient in principle, induction heating efficiencies can be significantly improved through the implementation of Dynamic Energy Management technologies such as state-of-the-art converters equipped with LLC-resonance circuits and improved zone heating technology. These new technologies support flexible and efficient production strategies, giving operators new freedom to optimize their process for each product and cut production costs.

Against a backdrop of increasing energy costs and tightening constraints on resource availability, the call for greater optimization and highly efficient induction heating has grown louder and louder. Innovative and inteligent strategies are now available to increase energy efficiency and production flexibility while simultaneously streamlining operations and reducing spare part costs. Together with laborsaving automation, improved energy efficiency offers the most meaningful productivity gains.

Recognizing this, the German federal government targets a doubling of 1990-level energy productivity by the year 2020. In a July, 2009 publication on energy efficiency, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety projects that a 20% to 40% decrease in energy consumption should be possible by 2020 under reasonable economic conditions. Dynamic Energy Management of modern induction systems can play an important role in the pursuit of these goals. Due to the high energy inputs required to heat metals, even modest electrical and thermal efficiency improvements lead to meaningful energy conservation.

Efficiency – the key to unlocking productivity

Efficiency is generally defined as the ratio of power output to power input as follows:

Efficiency = $\eta = P_{out} / P_{in}$, and

$P_{in} = P_{out} + P_{lost}$, where

P_{in} = power input (e.g., power taken from the grid)

P_{out} = power output (net power contributing to useful work)

P_{lost} = power lost due to system inefficiency

The total efficiency (η_{total}) of an induction system is calculated by multiplying the efficiencies of individual subsystems as follows:

$$\eta_{total} = \eta_{transformer} \cdot \eta_{converter} \cdot \eta_{capacitors} \cdot \eta_{inductor}$$

Inductor efficiency ($\eta_{inductor}$) is determined by thermal and electrical efficiencies as follows:

$$\eta_{inductor} = \eta_{th} \cdot \eta_{el}$$

The *electrical efficiency (η_{el})* is largely determined by the relationship between the workpiece (billet) diameter (di) and the heating coil diameter (D). These diameters should be appropriately matched to achieve high electrical efficiency. For ideal energy efficiency there would be a dedicated inductor for each and every billet diameter in the production schedule. A more practical approach is to examine the production schedule and designate a family of induction coils, where each coil is suitable for a range of billet diameters. The number and size of the coils represent a compromise between the competing objectives of optimal inductor/workpiece matching and operational flexibility.

Thermal efficiency (η_{th}) is primarily influenced by the heating cycle time and the induction heater train length. Recall that the rate of heat loss by radiation is proportional to the fourth power of the surface temperature (Boltzmann law). Thermal efficiency is therefore improved by minimizing the time interval that workpiece is held at elevated temperatures. The goal is therefore to heat the billet quickly and briefly, subject to process requirements for reliable, accurate and uniform billet heating. Radiation heat losses can also be reduced by insulating and/or lining the heater coils. In any case, optimal thermal efficiency requires optimization of the induction heater train.

Inductor efficiency strongly influences total system efficiency. Heating steel to the enthalpy temperature of 1250°C requires a specific energy input of about 240 kWh/ton. With an optimized inductor, the required system input power from the grid is less than 345 kWh/ton,

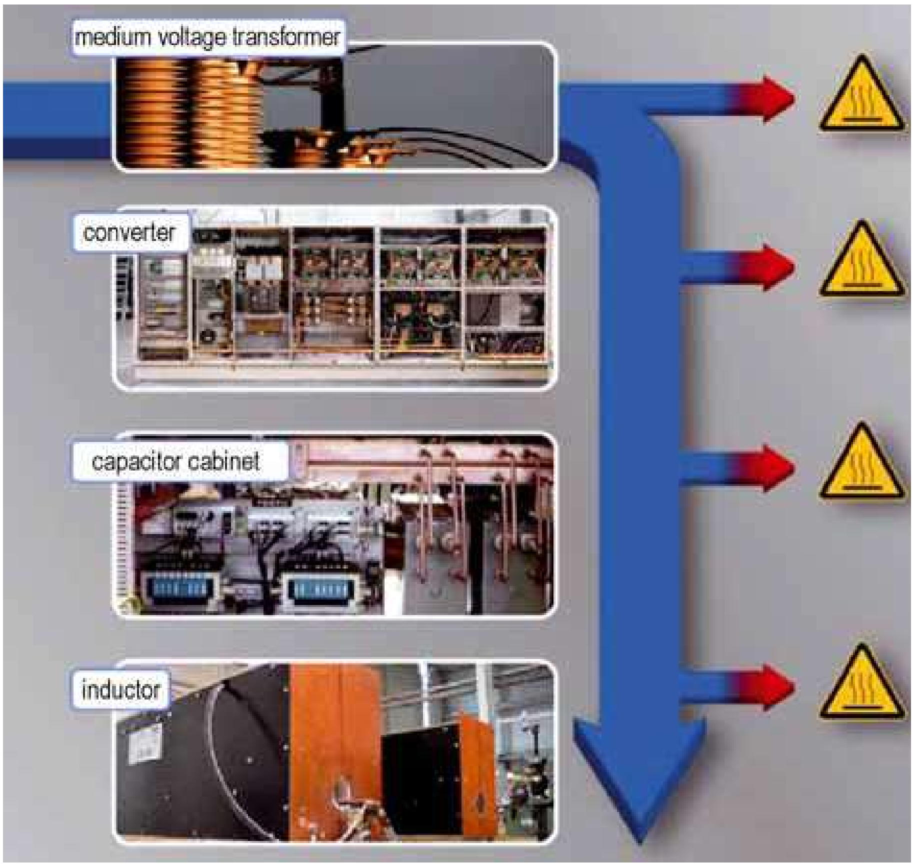

Fig. 1: Components Influencing the Efficiency of Induction Heating Systems

corresponding to an inductor efficiency greater than 75%.

The resonance circuit efficiency should be at least 97%, and is determined by the design and sizing of the capacitor battery and associated bus work.

Since transformers with off the shelf efficiencies of 99% are already available, there is little opportunity to improve operational productivity through additional transformer optimization (**Fig. 1**).

LLC Converter technology with efficiency advantages at reduced throughput

The key to unlocking higher induction heating efficiencies was the development of an entirely new generation of converters featuring LLC (inductor-inductor-capacitor) resonance circuits with switching at the inverter output. Comprised of an unregulated rectifier, intermediate circuit capacitor, IGBT inverter, and output choke, the inverter has the characteristics of a voltage source. The output choke decouples the inverter output from the parallel resonance circuit and adapts the output impedance to the load impedance (**Fig. 2**).

The output choke limits the frequency range according to system requirements, and should be matched to the resonant circuit. The operating frequency is determined only by the load. The inverter adapts to the resonance frequency of the load.

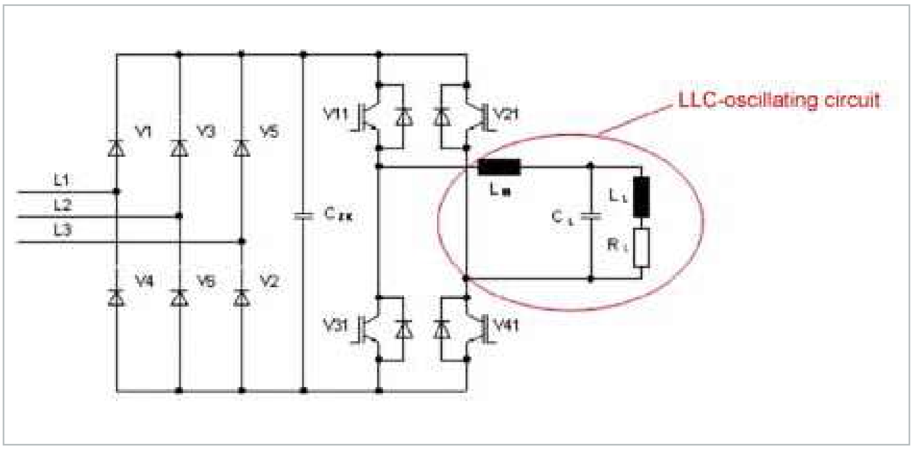

Fig. 2: Circuit Diagram of an Induction Heater LLC-Converter Module

In contrast to regulated rectifiers equipped with thyristors or MOSFETs, unregulated rectifier bridges with diodes can be used. The diodes maintain a constant DC voltage in the intermediate circuit. The implementation of intermediate circuit voltage inverters and LLC-technology yields a constant power factor (cos φ) greater than 0.95 (95%) across the entire load range. Moreover, the inverter efficiency is increased from 95% to 97%.

Modular converter architecture for individually tailored heating strategies

By standardizing on convenient nominal converter sizes it is possible to implement a modular approach to induction system design. Each inductor is supplied by a separate middle frequency inverter. In the past an inductor train would be equipped with various coils having differing numbers of windings to achieve a desired heating profile. By contrast, the new modular converter systems independently control the power and frequency of each individual coil in the inductor train, achieving custom heating profiles without the need for custom coils. Most importantly, the operator has the flexibility to specify the energy input for specific applications and use individual heating strategies optimally adapted to each heating task. Strategies to reduce scale formation and/or reduce energy consumption at lower throughputs can also be easily implemented. System maintainability and spare parts requirements are also improved through the use of standard modules. SMS Elotherm offers IGBT converters with

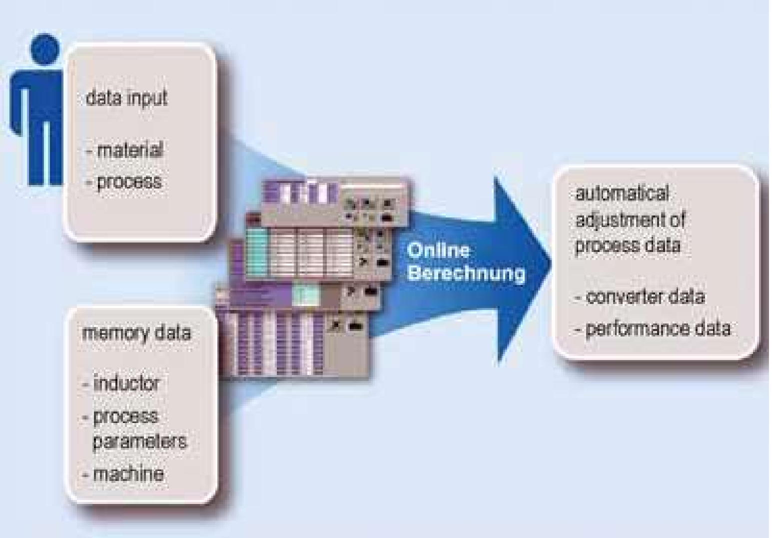

Fig. 3: Databank-Supported Expert System for Process Parameter Optimization

400 kW and 800 kW output power ratings as standard modules.

Maximum throughput is still the decisive design criterion for the inductor train layout, determining the number and length of the heating coils. With the advent of "*i* Zone" control induction technology, it is practical to quickly adapt the inductor train to changing throughput requirements. Today's state-of-the-art implementation of *i* Zone technology is the result of almost two decades practical development of the original zone control technology first introduced by SMS Elotherm in the early 1990s. This technology, developed particularly for the process control of modern induction heating systems, has enjoyed rapidly growing interest since its introduction under the *i* Zone trademark at the Hannover Fair in 2009.

i Zone databank-supported expert system for process parameter optimization

Based on the premise that each heating task should be accomplished with optimal energy efficiency, zone control technology optimizes the heating profile with feedforward control to the next process step. The *i* Zone control automatically calculates and implements optimal heating process parameters based on heating curves (recipes), material properties, system parameters, and an expert system databank. Maximum process stability and energy efficiency are the automatic result (**Fig. 3**).

Because *i* Zone technology can dramatically reduce CO_2 emissions, it is a natural choice for 1st – Tier Suppliers and OEMs to reduce their carbon footprint.

Moreover, *i* Zone technology offers a number of practical benefits for better heating productivity, such as:

- Minimal scale buildup
- System startup with preheated material
- Heat and hold operation during production pauses
- Minimal recycling and reheating, since even the last hot billet in the inductor train is still usable

In a wilderness of runaway costs, eroding prices, and declining margins, this trailblazing control system leads the way to productivity, process flexibility and profitability (**Fig. 4**).

For this reason, more and more energy-inefficient systems have been replaced with modern induction systems featuring *i* Zone Technology, contributing to a growing body of real production data to confirm the fast payback of this investment.

Conclusion

The principles of Dynamic Energy Management have been successfully realized in modern induction heating systems featuring improved inductors, resonance circuits, intermediate circuit voltage inverters, and LLC-technology to dramatically improve productivity and energy efficiency, particularly when systems are operating at less than their maximum rated throughput.

The *i* Zone Expert System provides a powerful tool to optimize resource utilization while reducing CO_2 emissions. Moreover, with its automatic optimization of critical process parameters, *i* Zone technology has demonstrated meaningful improvements in both manufacturing cost and product quality. ■

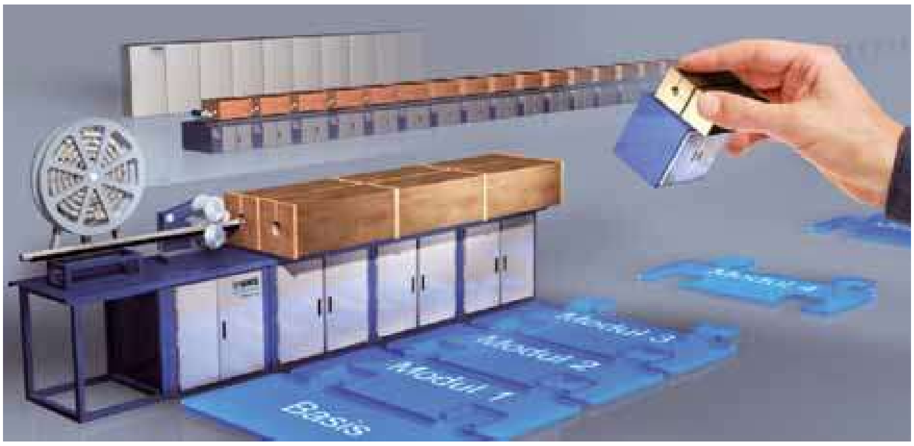

Fig. 4: Modular induction heating system

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