JUNE/JULY 2005

The IEE

Power Engineer

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Inside:

Marine generation: sink or swim

Power to the danger zone

Don't let emissions choke your profits

EDITOR'S LETTER

Rebecca Pool

Biofuel boom

Fed up with rocketing oil and gas prices giving you a heart attack each time you reach for the petrol pump but can't be bothered to wait for that all-electric car to hit the streets? Then perhaps it's time you topped up the tank with a biofuel, rather than your usual unleaded.

Biofuels – be they bioethanol, biodiesel, or plain old vegetable oil – are hardly new. In the late 1980s, more than half of the cars manufactured in Brazil ran on pure bioethanol, and today many car makers, including Ford and General Motors produce cars that run on 85%:15% bioethanol/petrol blends. However, a recent report from the US Oak Ridge National Laboratory suggests it could be time we paid more attention to the greener, cleaner alternative to petrol or diesel.

Researchers' calculations reveal that US forestland and agricultural land alone could provide more than 1.3 billion dry tonnes of biomass each year, providing enough biofuel to meet at least one-third of the nation's transport demand. As they point out, such a strategy would cut dependence on 'foreign oil', reduce greenhouse gas emissions by around 10% and boost rural industries.

Sounds great, but could Europeans replicate the same strategy? A European Union directive already recommends motor fuels contain 2% biofuel by the end of this year and 5.75% by 2010. Also, grain surpluses in the UK come in at around 1 million tonnes; these alone could be converted into bioethanol to provide nearly 5% UK petrol demand.

And recent encouragement from the International Energy Association may accelerate biofuel take-up. In its report – 'Biofuels for transport' – published earlier this year, the Paris-based organisation said biofuel could displace up to 5% of motor gasoline by 2010, if recent world initiatives are fully implemented. It also recommended pursuing global trade, pointing to sugar cane growing countries such as Brazil and India that produce low-cost bioethanol.

Costs aside, the biofuel movement has already started. UK supermarket giant Tesco is currently selling 'GlobalDiesel', a blend of 95% ultra-low sulphur diesel and 5% rapeseed-based biodiesel, manufactured by Greenergy, UK. The cost of the fuel is on par with its diesel equivalent and is said to have comparable fuel efficiency.

And according to UK organisation 'Biofuel' there are no real difficulties to overcome when using biodiesel. The fuel can be mixed in any ratio with petro-diesel, even in the fuel tank, and can be distributed using the same infrastructure.

Indeed, this ease of use may well have spurred the new wave of biodiesel plant build. Greenergy is in the process of building a £10m plant that will produce 100,000 tonnes of biofuel each year to feed a growing European market.

But how about something for the purists out there? Unfortunately, you may have to wait some time before you see hoards of cars running off neat bioethanol.

Bioethanol's lower energy density – relative to petrol – means a car would need to carry up to 50% extra fuel to travel the same distance as its petrol-fuelled counterpart. Meanwhile an 'ethanol engine' requires a modified fuel system to provide higher rates of fuel flow.

But for the time being, feast your eyes on a racing car designed and built by Team Nasamax, a consortium of engine designers and manufacturers. The vehicle is the first pure bioethanol powered car to take part and finish the French 24 hour endurance Le Mans, clocking a top speed of 318km/hour.

While this may be the stuff green dreams are made from one fact is clear: biofuels are no longer the clean distraction of yesterday. Real word demand is growing and it's set to change the face of energy markets as we know them today.

Turn to page 17 to read more on trends in the transport industry.

Rebecca Pool

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Cover photo courtesy:
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Power Engineer is published bi-monthly by the Institution of Electrical Engineers (IEE). The IEE is not as a body responsible for the opinions expressed in *Power Engineer*.

Annual subscription £185 ($315 in the Americas).
Details from sales@iee.org

UK ISSN 1479-8344

Web-offset printing by Wyndeham Heron Ltd,
Colchester, Essex, UK

January-December 2003 Average circulation 21,000

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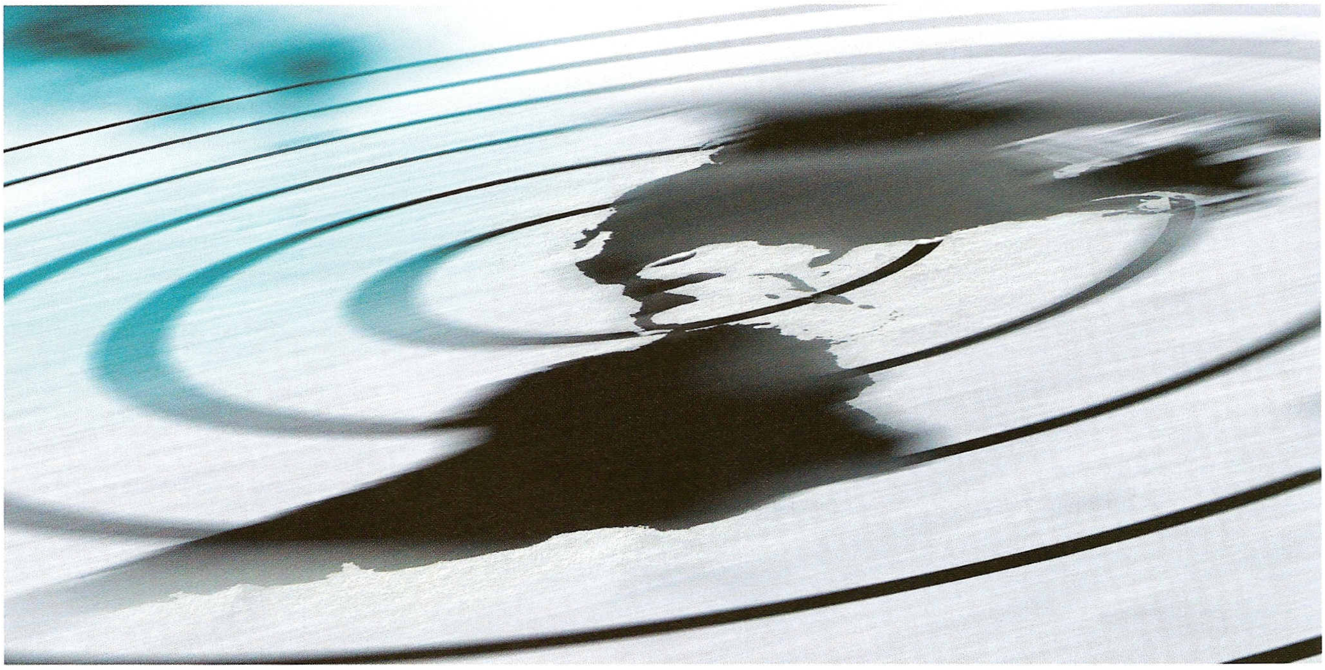

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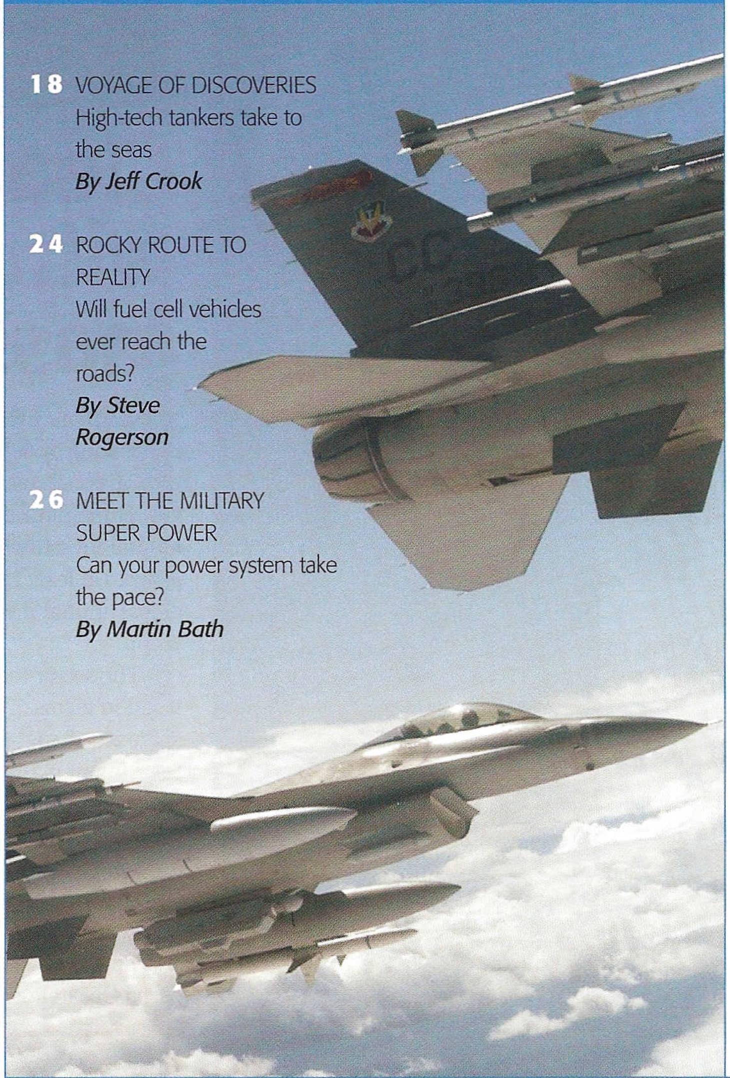
FOCUS ON TRANSPORT



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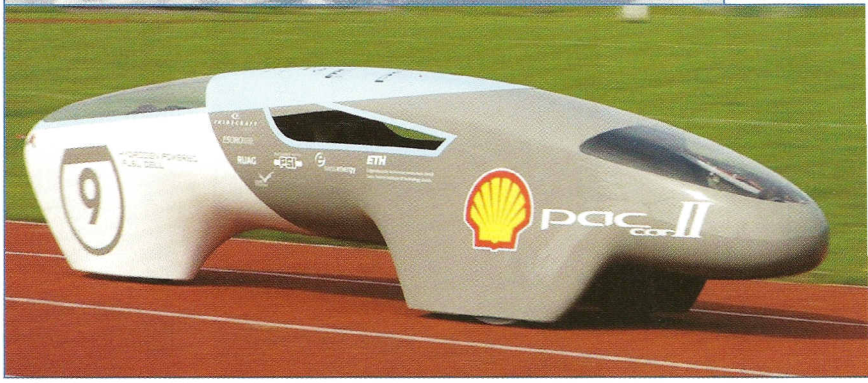

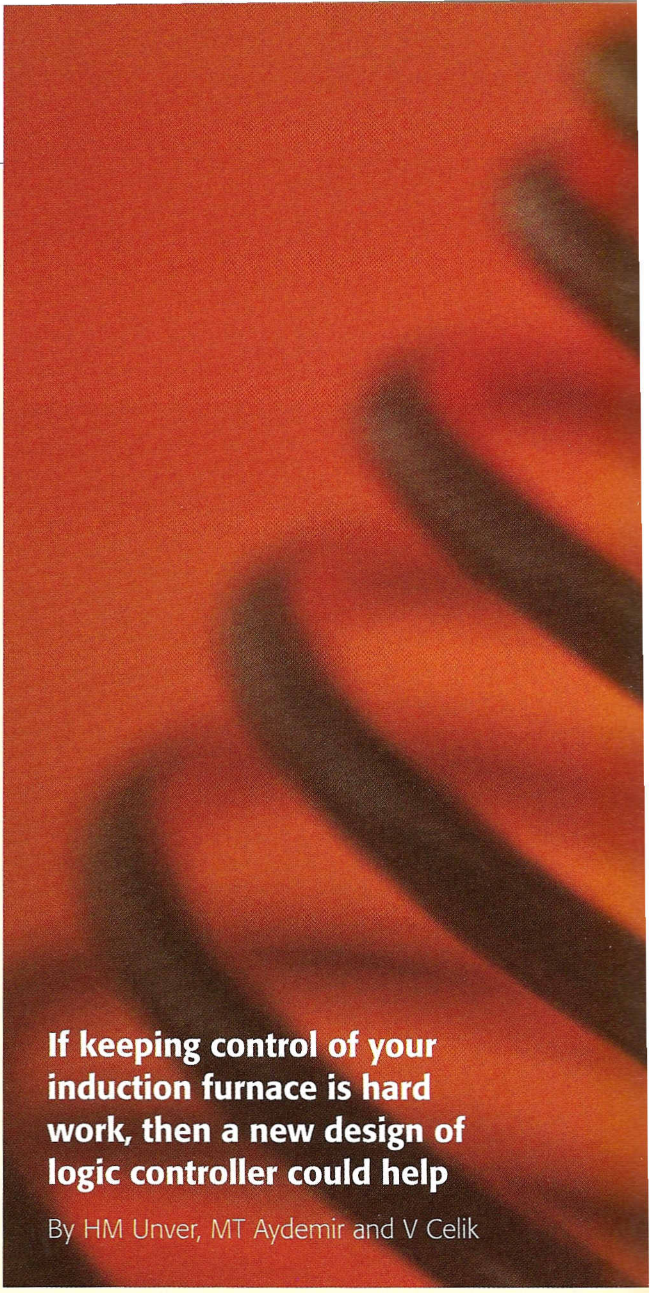

If keeping control of your induction furnace is hard work, then a new design of logic controller could help

By HM Unver, MT Aydemir and V Celik

The induction furnace may not be the sexiest of industrial equipment, but it has been used in a massive range of applications from heating, melting and welding to shrink-fitting, forming, soldering and even plasma physics. The furnaces operate between frequencies of 10Hz to 60MHz, and as a result, different power supplies – operating at different frequencies – have also been developed.

As power supply development has taken place, switching losses have dropped, safety at high frequency operation has increased and overall weight has reduced. At the same time, power semiconductor technologies have progressed and today, insulated gate bipolar transistors (IGBT) are commonplace in many applications. Indeed, low conduction losses and low gate power requirements have made IGBTs the primary switching device.

But, while induction steel heating furnaces (ISHF) have several advantages in practical applications, their design is complex. What's more, when a material is heated within an ISHF its resistivity and magnetic permeability fluctuate, which proves detrimental to the control of power within the furnace.

Looking first at resistivity, an increase in temperature leads to a rise in this material property, resulting in the material's total resistance (R) increasing. This, in turn, causes a significant drop in the power drawn from the supply.

Meanwhile, as the temperature of a material approaches its Curie point, its magnetic permeability (μ) decreases, eventually dropping to unity at the Curie point. This leads to a reduction in inductance (L) as well as a change in resonance frequency. As a result, the active power transfer from the supply decreases, increasing the time required to reach a given temperature. Thermal losses will also extend the time to reach the desired temperature point.

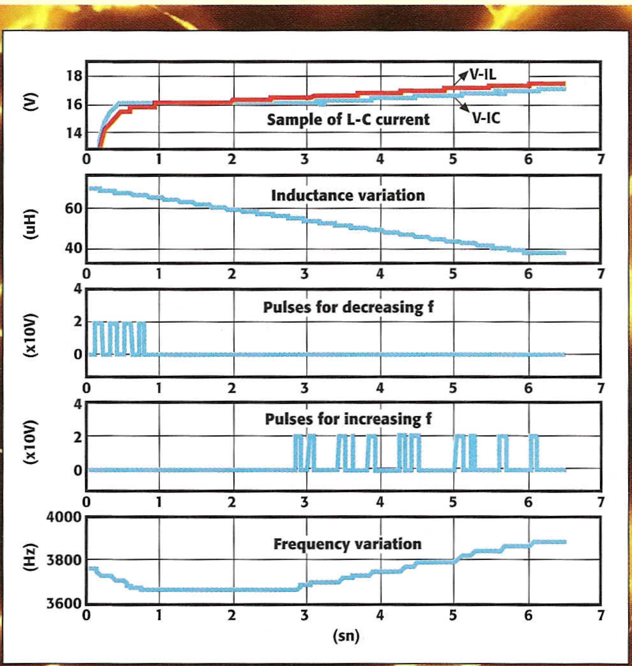

Fig 1: Resonance frequency adjustments (simulation results in MATLAB Simulink)

So what can be done to improve power control within an ISHF? One way to tackle the problem is to use a programmable logic controller (PLC). Indeed, modern PLCs are modular, affordable, have large memory capacities as well as special functions such as pulse wave modulation (PWM) and data communication.

Using a PLC not only eases position, temperature and pressure control within the ISHF, but also provides over-voltage and over-current protection. A new PLC control system design, however, has allowed heating to take place at constant power while maintaining a steady resonance frequency.

MEET THE SYSTEM

Several researchers have developed PLC control systems based on a parallel resonance concept, with the resonance frequency being determined by a phase locked loop (PLL).

Control freaks

However, these systems are complicated, difficult to calibrate and sensitive to noise.

As a result, researchers have looked for simpler and more reliable ways of implementing a system to determine resonance. The control algorithm adopted in this work was based on the following:

In parallel resonance circuits, the inductor current (I_L) is larger than the capacitor current (I_C) when the operating frequency is below the resonance frequency. When the operating frequency is above the resonance frequency, the inductor current is lower than the capacitor current. The currents are equal at the resonance frequency.

MATLAB Simulink software was used to model a simple control scheme and achieve the desired output (fig 1). For the operation of the controller, the switching frequency (fs) was initially higher than the resonance frequency (f_o). Therefore the capacitor current was higher than the inductor current, and the controller acted to decrease the switching frequency to catch the resonance frequency.

In order to simulate the real system as closely as possible, the inductor value was allowed to change linearly during the simulation. After some point, the controller decided to increase the switching frequency so that the system was kept in resonance.

For hardware implementation of the PLC program, the researchers selected Siemens's S7-200/ CPU 214 model. The PLC has 14 inputs, 10 outputs and pulse width modulation (PWM) and pulse train-out (PTO) generators, which can be directed to two outputs (Q0.1 and Q0.2).

The PLC also has the input-output capability to perform certain functions such as placing and removing the work piece as well as temperature, pressure and position control. A response to over-current, over-voltage and short circuit protection signals can also be configured into the PLC.

The written PLC program has two main components (fig 2). The first generates the necessary pulses for the inverter while the second is responsible for the control of the induction furnace.

The PLC's I0.0 and I0.1 inputs can be used as interrupt inputs, and depending on their status, a four-bit region is defined in the memory. Once defined, it is aimed to transfer the commands for altering the PWM pulse periods or duty cycle to the PLC.

Since there are only two interrupt inputs in the PLC system, another input (I0.3) is used to determine which one of the two parameters – duty cycle or frequency – will be operated. An electronic switch is used to adjust the period and duty cycle of the PWM generator. An electronic

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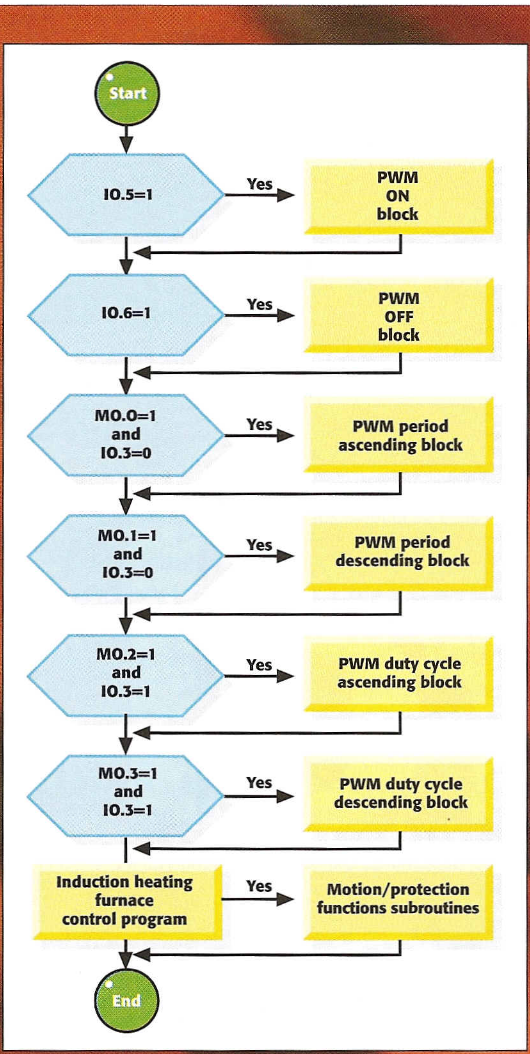


Fig 2: Flow Chart for the PLC Program

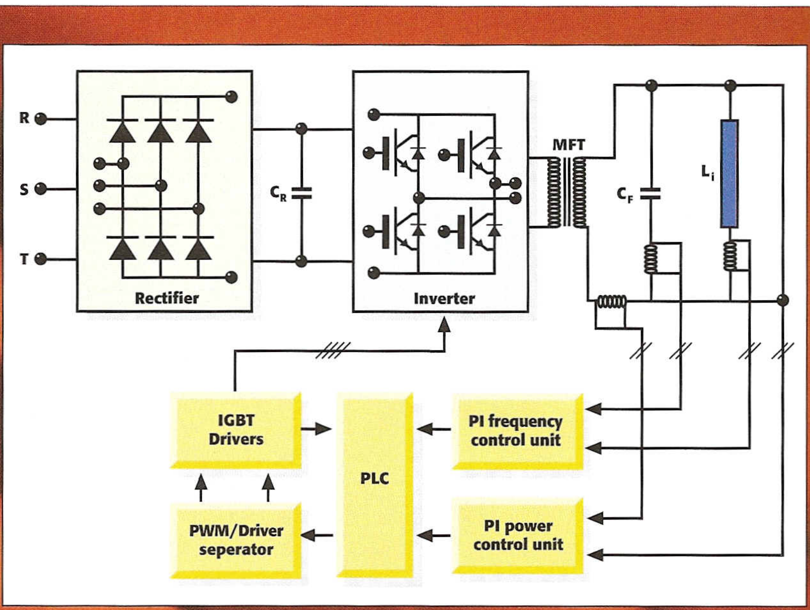


Fig 3: Designing the induction steel heating furnace.

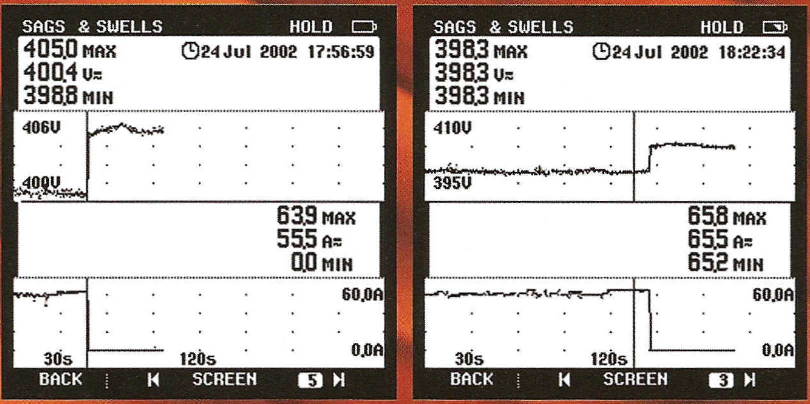


Fig 4: AC Line voltage and current variations with controlled operation (a) pipe (b) solid cylinder

Time [s]	0	15	30	45	60	75	90	105	120	135	150	160
V [V]	226.9	220.7	212.0	209.2	197.8	194.6	233.8	258.6	268.8	273.2	275.0	275.7
I [A]	17.10	17.19	17.35	17.64	18.85	17.88	16.62	16.10	16.09	16.15	16.26	16.31
S [kVA]	3.88	3.79	3.68	3.69	3.73	3.48	3.89	4.16	4.32	4.41	4.47	4.50

Table 1: Numerical values for the secondary side voltage and current in uncontrolled operation

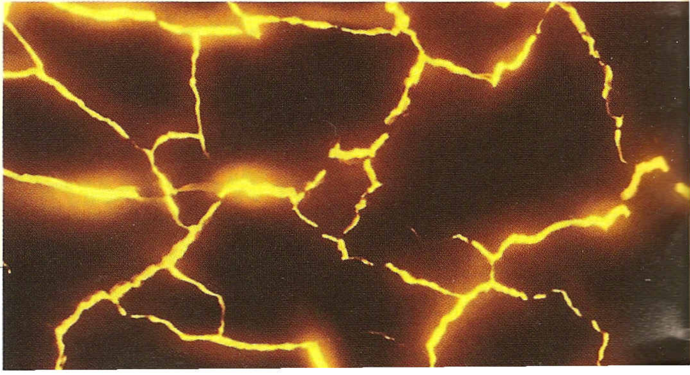
circuit has been designed to determine the position of the electronic switch, which provides an input to I0.3, based on the signals generated by PI control units. Priority is given to resonance frequency adjustment.

The program can also automatically determine the period and the duty cycle, based on the feedback signals sent by the PI control units, although manual operation is optional. The program can be adapted to determine pressure, temperature, over-current and over-voltage as well as enable short circuit protection, turn-on and turn-off operations. Structural programming was used with transfer to the interrupt modules taking place via the main program and subroutine definitions.

The system itself consists of a control unit, a power unit, a high frequency transformer (MFT) and a resonant tank containing a capacitor and heating inductor (fig 3). The power unit consists of an AC/DC/AC converter and provides up to 60kW output power at any frequency between 5Hz and 10kHz.

A three-phase uncontrolled rectifier has been placed at the front of the converter with the output being taken from an inverter with voltage and frequency control. The rectifier section contains 100A, 1200V three-phase half-bridge diode modules. Meanwhile, the single-phase inverter uses two half-bridge IGBT modules, with rated values of 200A and 1200V. The CPU generates the PWM signals that are applied to the gates of the switches. The positive alternance pulse is applied to the upper switch while the other one is applied to the bottom switch.

PI controllers are used in the frequency control unit.



Current samples received from the inductor and capacitor are separately converted to voltages and then filtered. Each signal is passed through a PI regulator.

The PI regulator outputs are applied to a differential amplifier, the bandwidth of which can be adjusted. Finally, the output of the differential amplifier is used to control the PLC drive.

The power control unit also has a PI regulator. Load voltages and currents are detected, rectified, filtered and multiplied, and then passed through a PI regulator.

A differential amplifier amplifies the difference between the output of the regulator and the reference value. This amplified signal is used to control the PLC driver.

A mid-frequency transformer is also used, which has a turns ratio of 10/25 and rated values of 500V/1250V and 55kVA. When building the transformer, 0.1mm thick, 35000 Gauss laminated steel was used.

TESTING TIMES

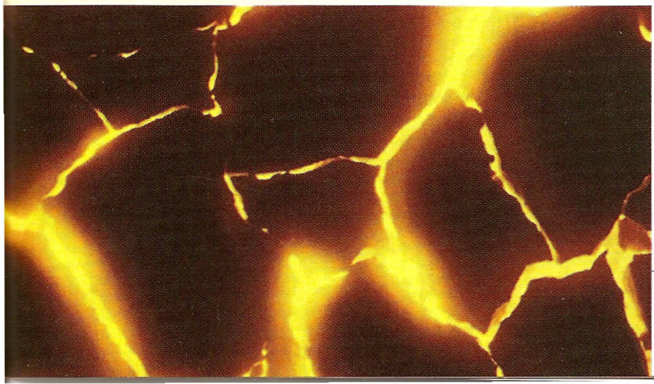
Initial computations performed on a pipe material showed the cold value of the inductance to be 67.8μH, with this value dropping to 63.17μH on heating. Similarly, the resistance increased from the cold value of 16.3μΩ up to 13m.

To achieve a resonance frequency of around 3kHz, a 28.82μF capacitor was used. Given these conditions, the initial resonance frequency was 3600Hz (see equation1). When the material temperature reaches 1250°C, a resonance frequency of 3730Hz is obtained.

Numerical values for the secondary side voltage and current at the initial resonance frequency are shown in Table 1. The increasing values following the minimum point should not be misinterpreted as a power increase.

The phase difference between the fundamental components of the voltage and current was found to be as high as 60° and the system was operating in the inductive region. As the power drawn in this region was very low, the temperature did not settle at 1250°C in 25s as would be expected, but took 160s to reach 900°C.

Using the control unit, the system was then used to heat a pipe and a solid cylindrical material (fig 4). The power factor (PF) at the input was measured as 0.89 for the pipe and 0.93 for the solid cylinder. The power (P_p) in the pipe heating was calculated as 19.8kW (equation 2) while the power for the solid cylindrical material case (P_S) was 24.3kW (equation 3). The current and voltage variations were found to be within the acceptable limits of ±3%.



Frequency analysis of the high frequency transformer revealed that the primary power was 18.6kW at a 0.79 power factor, with a displacement factor of 0.99. The instantaneous resonance frequency of the system was 3.73 kHz.

Meanwhile, for the secondary side voltage, current and frequency, a measurement of ~330V and ~54A was read at 3.73 kHz. The fundamental voltage and current waveforms were shown to be in phase indicating that a resonance condition existed. Given a power factor of 0.79, the total power was found to be 15.6kW (equation 4).

The power difference between the input and output was mainly due to losses in the mid-frequency transformer. However, designing and building a more efficient transformer would cut these losses.

Additional analysis of the secondary voltage, current and frequency data – with the system operating at an input power level of 55 kW – showed the secondary power to be 48.4kW.

So what can we conclude from this work? Firstly, a system suitable for PLC control in an induction steel heating furnace has been successfully built. Indeed, tests using a range of capacitor and inductor values have revealed that the new system follows resonance frequency and power variations.

$$1:\ f_0 = \frac{1}{2\pi\sqrt{L.C}} = \frac{1}{2\pi\sqrt{67{,}8.10^{-6}.28{,}82.10^{-6}}} = 3600\ Hz$$

$$2:\ P_p = U.I.PF = 400.4x55.5x0.89 = 19777.758 \cong 19.8\ kW$$

$$3:\ P_s = U.I.PF = 398.3x65.5x0.93 = 24262.445 \cong 24.3\ kW$$

$$4:\ P_i = U.I.PF = 329.8x53.9x0.79 \cong 15.6kW$$

Check the equations

The next stage of development is to introduce analog input and output ports, in order to achieve PID control inside the PLC. This will allow other control cards to be removed from the system. Additional control techniques, such as adaptive control, fuzzy logic and artificial intelligence techniques can also be used in this system.

What is clear, however, is that the system enables the control of a range of processes. These include material loading, material selection depending on time of the day, responding to fluctuations on the AC line voltage, and interactions between units following heating. ■

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