کوره القایی

روش کنترل دیجیتالی کوره القایی

DIGITAL CONTROL FOR INDUCTION HEATING

DIGITAL CONTROL FOR INDUCTION HEATING SERIES SWITCHING GENERATORS

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Abstract
A digital control for induction heating has been developed and tested. The control of the generator can be achieved by controlling three different loops. Only one of them is active depending on the application. In addition to this control loop, a certain number of limitation loops are available to avoid an illegal or dangerous operation of the system. The control loops are 4th order IIR structures realized as a cascade of two second-order blocks. A dominant pole is placed at very low frequency to assure stability under unexpected conditions.
The design cycle began in January 1999 with a rough specification and a partial knowledge of the system dynamics and some results were expected for the end of the year. Given these constraints, the prototype board maintained most of the well-established blocks of the previous analogue version and substituted processing and measurement blocks. A D.module.C31eco module from D.SignT, based on the TMS320C31 floating-point DSP from Texas Instruments, was selected as the processing unit. The prototype has been working in real conditions on a 50kW low switching frequency series generator.

Objective
A digital control for induction heating machinery had to be developed and tested. GH Electrotermia is a company located in San Antonio de Benageber (Spain) with more than twenty years of experience on transistor-based induction heating resonant generators. These generators are superior to traditional electronic valves generators in efficiency, maintenance costs and reliability. To increase performance and get a higher control of the systems they pretended to migrate their well-proven analogue control to digital and include some additional capacities (mainly flexibility, user-interface and connectivity).
The final objective of the company is to develop a flexible digital control for their resonant and parallel transistor-based generators. The problems involved in this ambitious idea range from assuring immunity of digital control in a highly hostile electromagnetic environment to optimizing control loops. To assure the feasibility of the approach a first objective was fixed as “Design, build and test a DSP-based control for a fully operative 20kHz series inverter in a 12 months period”.

Principles of Induction Heating
Induction heating can be applied in a variety of industrial processes involving heat treatment of metals, including melting, through heating, hardening, brazing, and welding. Other applications, such as semiconductor processing are also well suited for induction heating. In these processes, characteristics of the load are important in considerations involving proper matching of the workcoil and the power supply.
Induction heating exploits the electromagnetic induction discovered by Faraday in 1831. By subjecting a piece of electrically conductive material to a varying magnetic field, eddy currents are induced in the material. The induced currents result in I^2R losses and heat dissipation within the material.
The varying magnetic field is obtained by applying alternating current to a coil located in proximity to the heated material. Due to a skin effect, currents induced in the load are concentrated on the surface of the material. Similarly, coil current is concentrated on the surface of the coil. Nearly all of the loss occurs in about a skin depth. This fact is extensively used in surface hardening, where high frequency currents are induced on the surface of the material, resulting in a controlled temperature profile within the material. In through heating applications, however, skin effect hinders uniform heating of the piece.
Coil design, power, and frequency are selected by a metallurgist, often based on extensive computer-aided design and analysis process. For the power supply designer, it is sufficient to know the range of the loaded impedance. Basically, the load of an induction heating generator is an inductor in which the piece to be heated is allocated. A direct feeding of the heating coil would result in a too high ratio of

apparent power to real power, therefore compensation of the heating coil is needed. Compensation is carried out by a capacitor dimensioned in such a way that the power factor will be close to unity at the working frequency. The compensation capacitor can be placed in series or parallel with the inductor. In the first case, the load acts a current source (inductance in series) and therefore it has to be fed by voltage source (voltage-fed inverter). In the second case, when the load is a parallel-resonant circuit, it will react like a voltage source (capacitor in parallel) and therefore it has to be fed by a current source (current-fed inverter) [1].

Project development and description

Induction heating is a particularly critical application because part of the electronics works in extreme conditions so any error in the control can result in a breakdown of the power transistors, which are quite expensive. Therefore, rather conservative schemes must be applied to avoid it.

The design cycle began in January 1999 with a rough specification and a partial knowledge of the system dynamics and some results (on the reliability and performance a digital system) were expected for the end of the year. The uncompleted knowledge of the induction heating dynamics is due to its great dependence on the coil or material used in each machine, which can be quite different given the infinite range of coil topologies, materials and energies provided.

Three teams were set to carry out the project, one in G.H. Electrotermia, and two in the University of Valencia. The group in the company was supervised by E. Dede and offered expertise in induction heating, industrial applications and machine performance. In the University, a team from the LEII group, headed by E. Sanchis, gave expertise is power electronics and inverters. Finally, members of the GPDS (Digital Signal Processing Group), supervised by J. Calpe, worked on digital control strategies, DSP implementation and CPLD design.

The control of the generator can be achieved by controlling three different loops, i.e. voltage applied to the resonant capacitor, output current of the inverter, and power applied to the load. Only one of them is active depending on the application. In addition to this control loop, five limitation loops are available to avoid an illegal or dangerous operation of the system (there are thresholds for: i) frequency of the VCO that controls the power applied to the load; ii) voltage applied to resonant output capacitors, iii) current through load; iv) switching transistor losses; and v) DC link voltage). Six analogue channels are sampled (other two of the previously implemented in the analogue version of the control are replaced by indirect measures based on digital calculations).

A series of binary alarm and error signals must be checked as they may affect the functionality of the system and they must be sent in a packet to the user interface unit (Fig.1).

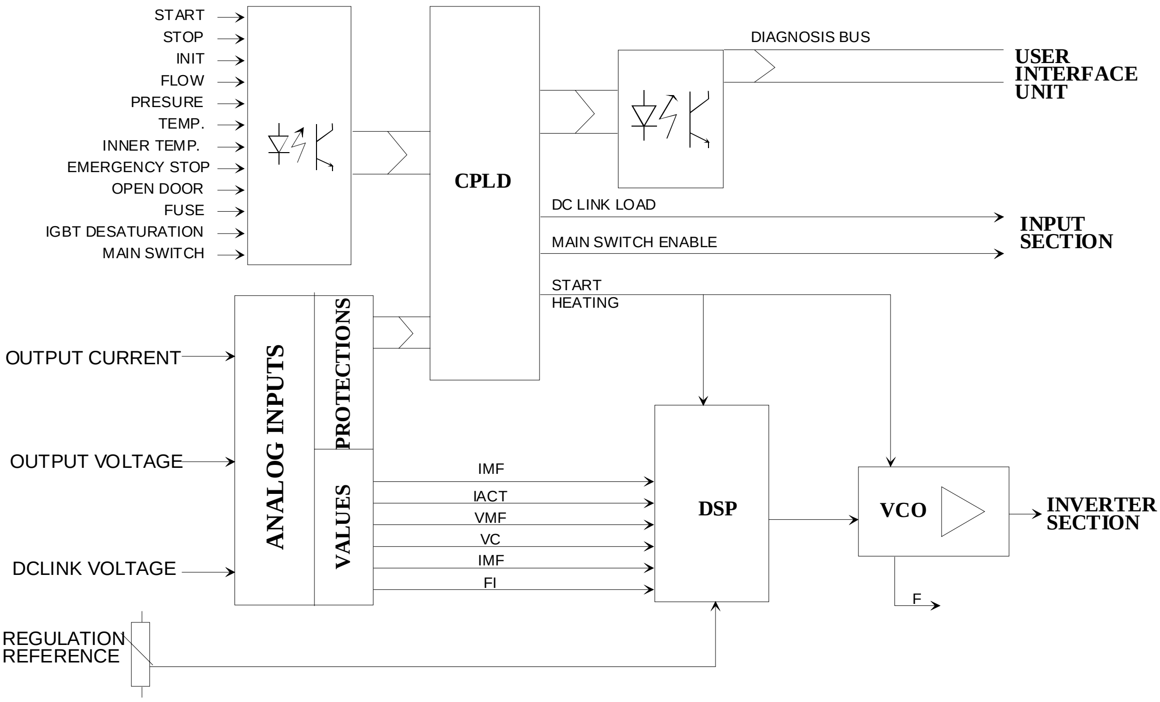

Fig.1- Block diagram for the digital control

Given the design parameters and the short expected time-to-market, the prototype board maintained most of the well established blocks of the previous analogue version and removed the processing and some measurement blocks. The bandwidth of the system was thought to be around 4kHz and resolution was estimated in 12 bits for A/D and D/A converters. Noise was assumed to be a real danger for digital circuitry performance so special care had to be considered. As far as the dimensions of the original board had to be kept unaltered and a four-layered board is considered necessary to assure immunity in the digital control area, the idea of a small-sized module containing the DSP and digital circuitry, inserted on a ‘mostly’ analogue board, gained interest.
A D.Sign.T.C31eco module from D.SignT, Kerke (Germany) was selected as the processing core [2]. This credit-card-sized unit is based on the TMS320C31 [3] floating-point DSP from Texas Instruments, Houston (TX) running at 60 MHz, with 128KB flash memory 64Kx32 SRAM, a CPLD that provides 16 fully configurable I/O ports, and an RS-232 port with an XON/XOFF protocol. It may be programmed in ANSI C or assembler, and provides a JTAG channel for debugging. We used the GoDSP environment for debugging and first analysis purposes [4].
Additionally, an XC95108-20 CPLD from Xilinx Inc., San Jose (CA) should be added to manage interface and decoding tasks. A CMOS High-Speed 12-bit ADC was used to sample the signals and a dual 12-bit DAC to provide the voltage output of the control algorithm for the VCO and the power measurement used for control and monitoring purposes (Fig.2).

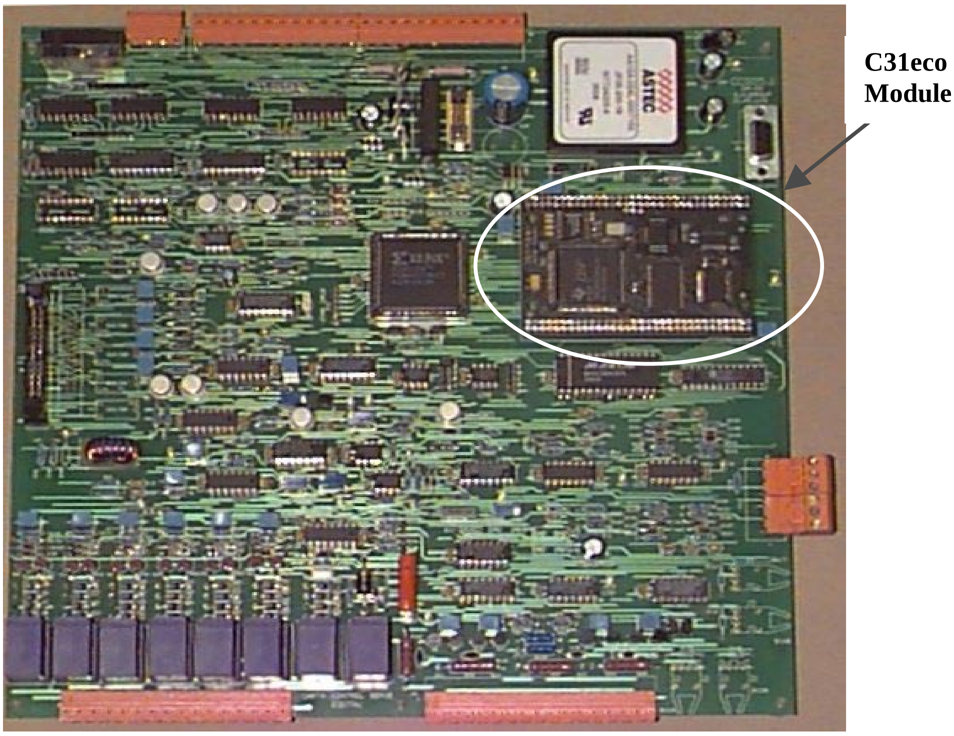

Fig.2- View of the DSP-based control PCB

The control loops are 4th order IIR structures realized as a cascade of two second-order blocks. A dominant pole is placed at very low frequency to assure stability under unexpected conditions. The analogue transfer functions were taken as a base for the digital design and a bilinear transform applied, additional changes were included to increase the phase margin and response speed. Sampling frequency was fixed about 20 times higher than the frequency of the highest pole or zero in the control loops [5]. Special generator modes such as ‘softstart’ and ‘softstop’ that were quite tricky and critical with analogue control revealed extremely simple and robust in the digital version. A flow-chart for the control included on the DSP is shown in Fig.3.
The prototype has been working in real conditions on a 100kW low switching frequency series generator for a time so the company has validated the design. Anyway, the control can be applied to the full range of series generators (from 20kW to 200 kW) available from G.H. Electrotermia with changes in the values of the filter coefficients.

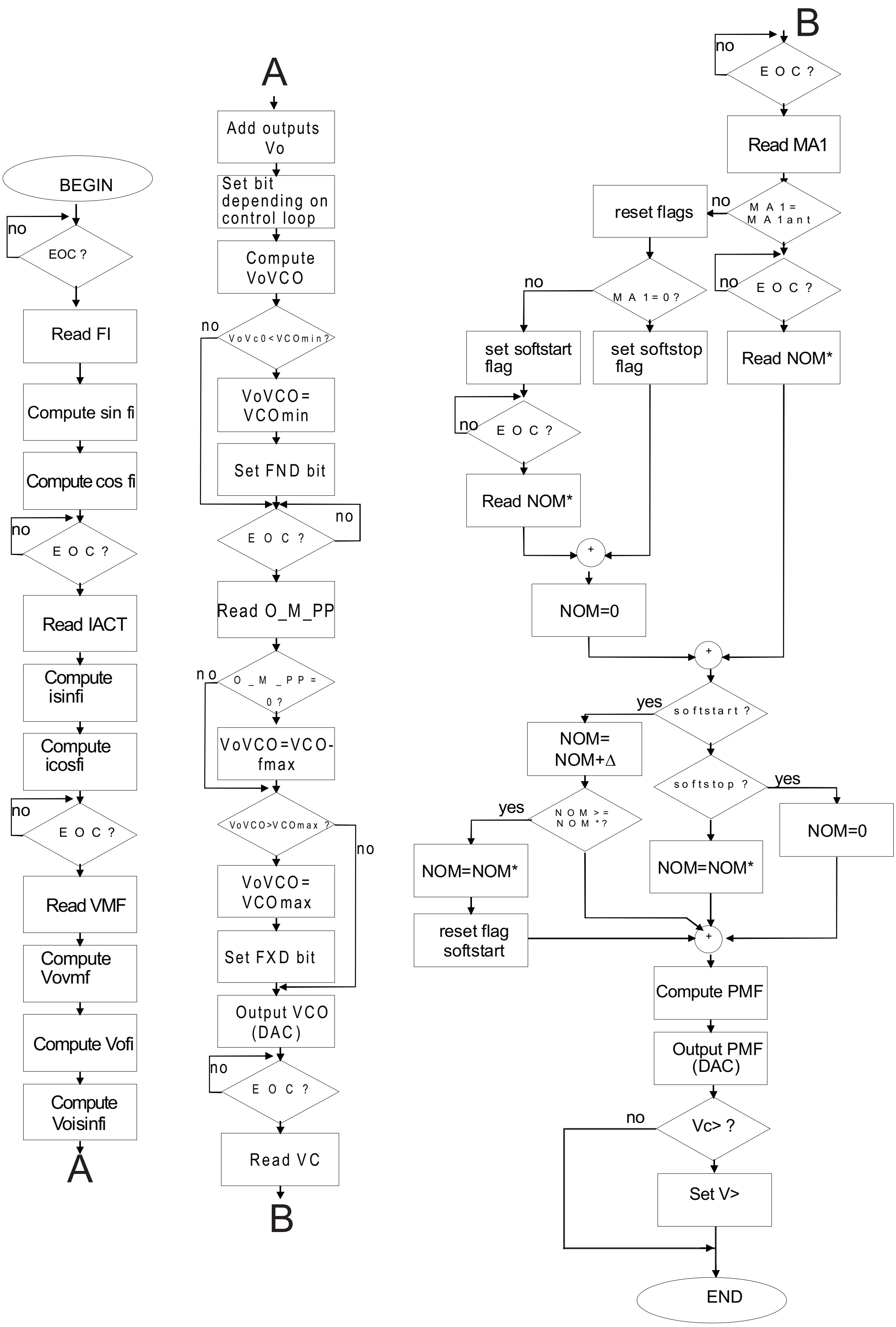

Fig.3- Flow diagram of the control algorithm

Conclusions

The first revenues of the analysis were a drastic reduction in the required bandwidth for control (it has been reduced more than an order of magnitude) and a redesign of the parameters in the control loops. Real tests have shown that 10-bit offer enough resolution for accurate control of the VCO and simulations have been carried out to analyze fixed-point arithmetic effects.
Electrical interference gave the expected problems especially in the CPLD and converters sections that share PCB with analogue components. Required robustness was achieved by heavy internal filtering of the CPLD digital inputs. The most sensible option seems to be redesigning the control multi-layered board to include converters and programmable logic devices.
The most valued advantages of the new approach are the programmability of the parameters, the introduction of more accurate soft-start and soft-stop modes and the simplification of the board layout.
A redesign of the system is expected given the experience gained during the design and including interconnectivity capabilities that integrate the induction heating generator in the plant fieldbus and allowing remote programmability and monitoring.

Future Plans

As previously stated, the main objective of this first stage was to demonstrate feasibility and robustness of the approach. This has been successfully achieved and the project is evolving in three directions:

1) Using the platform to perform a more accurate analysis of control dynamics. This is easier with the new control as direct access to both direct measurements and loop performance is provided.
2) Employing microprocessors opens new perspectives for machine usage and supervision. G.H. Electrotermia presented in 1998 a system for remote access to their products through Internet, with the DSP-based control the remote supervision will be more complete and informative.
3) After fixing the first two points a more compact and adjusted (therefore cheaper) board should be designed. TMS320F243 seems to be the choice for a number of reasons: i) fixed-point has been demonstrated to yield good results after theoretical analysis and simulations; ii) enough A/D and D/A converters are provided on-chip and 10-bit resolution has proved suitable; iii) availability of an on-chip CAN controller, and iv) enough on-chip memory resources.

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Authors Profile

Javier Calpe, (1966) received his B.Sc. in 1989 and his Ph.D. degree in 1993 in Physics from the Universitat de Valencia (Spain). Since 1991 he has been with the Department of Ingenieria Electronica at the University of Valencia, where he belongs to the GPDS (Digital Signal Processing Group). He is an Associate Professor. He holds an industrial patent, has co-authored more than 40 papers in scientific magazines and 80 communications to congresses. His research activities include digital signal processing and its industrial applications and power spectrum estimation.
Enrique J. Dede, (1948) received the MSc and Ph.D. degree from Valencia University, Spain. He is currently Full Professor in Power Electronics, and he is also R&D Director of G.H. Electrotermia, Spain. He is a holder of patents in the USA, Spain, UK and France on high-frequency power converters. The focus of his activities includes induction heating, high-voltage power supplies and high-frequency power supplies.
Esteban Sanchis, (1967) received a M.Sc. in Physics in 1990, and spent two years as a researcher to the European Space Agency in ESTEC, Noordwijk (NL). Joined the LEII Laboratory of the University of Valencia, and obtained his Ph.D. in Electronics Eng in 1997. At present he is an Associate Professor at the University of Valencia. His main areas of research are high efficiency, low power conversion techniques for space applications, high power resonant converters for industry applications and control.