A MODULAR DESIGN OF ASYNCHRONOUS TRACTION DRIVE

G Crawshaw, C J Yarrow, B J Cardwell

BRUSH ELECTRICAL MACHINES LTD U.K.

INTRODUCTION

It has been generally acknowledged that microprocessor and Gate Turn Off thyristor (GTO) technology has made a major contribution to the advancement of Variable Voltage Variable Frequency (VVVF) inverter drives. Particular benefits include supply harmonic control and the avoidance of chopper supply stabilisation for DC supply systems. This paper describes one approach to the design of such a system which is intentionally equally applicable to Locomotives, Electric Multiple Units (EMU), and Light Rail Vehicles (LRV). In order to achieve this, a modular approach was taken. The design was structured so that any specific system design could be constructed from a standard set of parts. These are then assembled into a single unit as required for the application.

The design is basically separated into the control electronics and the power electronics and is illustrated by its application to an EMU operating on Network Rail's 750V DC third rail system.

CONTROL ELECTRONICS

The control electronics is based on a microprocessor system designed specifically for traction systems and has been proven in previous applications. This is a 16-bit rack system comprised of several standard modules:

Control Microcomputer board
Analogue Input / Output interface
Digital Input / Output interface.

These are interconnected via the main interface bus, and perform the overall system supervisory functions, interfacing to the vehicle control and transducer systems, as well as providing the in-built diagnostic facilities.

The system is structured to provide computing capabilities at levels subordinate to the main system. In this application two such levels are provided within a single drive controller module to provide the torque control and pulse width modulation (PWM) functions. Each of these functions uses a 16-bit microprocessor. The interfaces between functions and to the system bus are via dual port memory (Fig. 1).

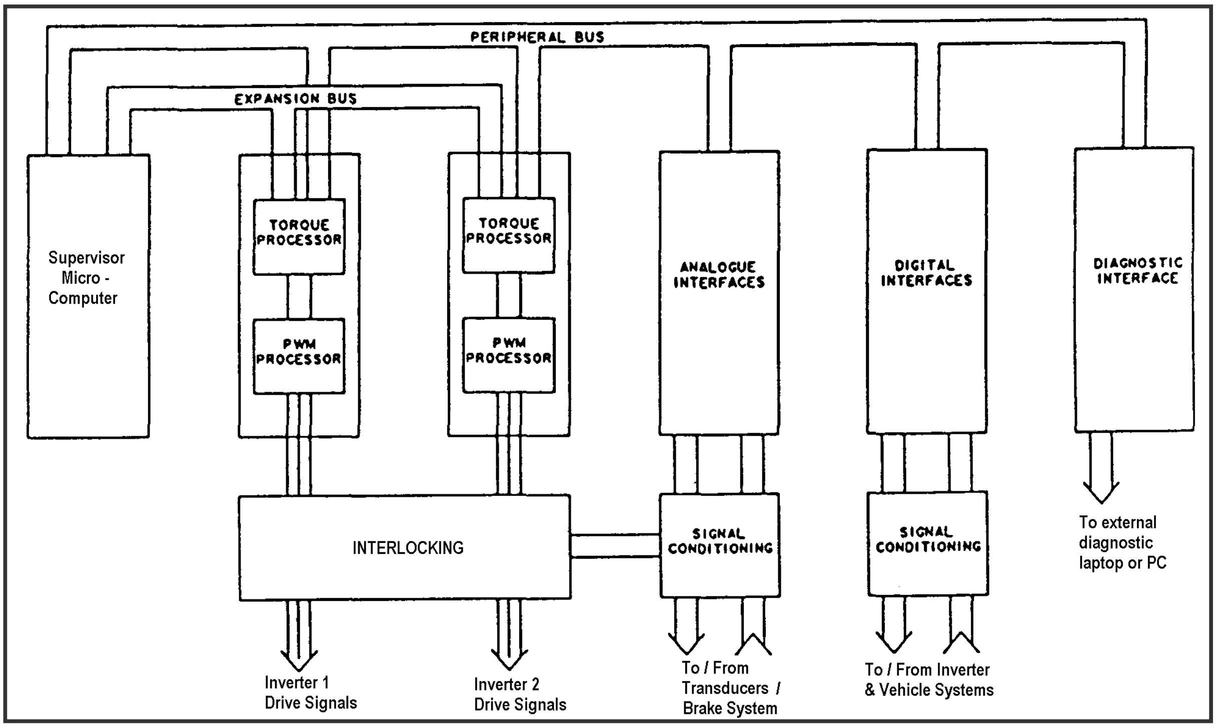

Fig. 1 CONTROL ELECTRONICS STRUCTURE

The whole of the microprocessor rack system is contained in plug in modules of a shielded metal construction, in such a way as to provide a screened enclosure for noise immunity. All signals going in and out of the micro-system are filtered to stop conducted noise. Signal conditioning is performed outside the screened enclosure using normal analogue electronic techniques. The fast signals needed for power circuit switching are taken directly out of the micro-system using fibre optic links.

Most of the software is written in Pascal, a structured high level language, producing good readable code and easier program documentation as well as ease of modularisation and design. All software is produced under vigorous quality assurance procedures, equivalent to SIL 2 for railway applications.

Supervisory System

As well as generally controlling the inverter system operation, the supervisory system contains the interfaces necessary to condition the power control to the vehicle requirements and provides brake blending. load weighing, notch regression and speed limit controls. All of these software modules may he tailored to suit any particular customer specification.

The diagnostic system is also incorporated at Supervisor level and handles all the diagnostic information built into each part of the system. It determines the action to be taken as a result of fault reports and provides communication to the vehicle system or to other data links as required.

Torque Control

The torque controller provides inverter frequency control without the need for any speed measurement, although a simple speed measurement is used to speed up the resynchronisation (re-motoring) process. The system is dependent only upon the two transducers needed to measure the DC input power. This means that the reliability of the control system is no worse than that of a chopper control. The control algorithm has been designed to have a minimum acceleration lag, which gives an accurate and repeatable torque-speed characteristic even at low speeds (1).

The following list of requirements is included in the specification of the control scheme:

i) The capacity to control more than one motor from each inverter.

ii) Good accuracy of achieved torque.

iii) No speed or flux sensors to be essential.

iv) The detection and correction of wheel slip/slide, including creep control.

v) Control bandwidth greater than 5Hz.

vi) The resulting software able to control motors over a wide power rating range.

vii) To prevent torque pull-out of the induction motors.

PWM Generator

The pulse width modulation system is carried out on the same printed circuit board as the torque controller. A harmonic elimination (or optimal) method is used. Most effort in this area has been directed at minimising DC supply system harmonics at selected signalling frequencies. There are other benefits resulting from the PWM strategy; mechanical stresses and noise are reduced because of the reduction in torque ripple, and also the motor heating caused by harmonic currents is reduced.

INVERTER POWER CIRCUIT

The inverter power circuit has been designed to be as simple as possible in order that reliability is maximised. Each of the six switches employs a single GTO switch. One arm of the bridge is depicted in Fig. 2, showing the anti-parallel diode and snubbing circuits.

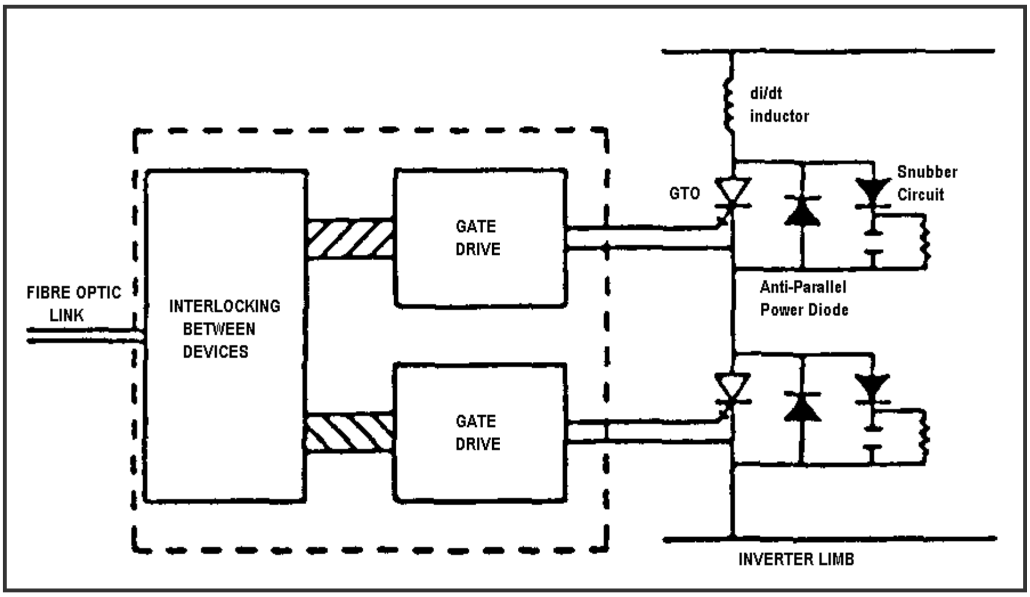

Fig. 2 ONE ARM OF A VOLTAGE SOURCE INVERTER

The gate drive circuits are arranged as a module per bridge arm. This allows the two gating circuits to be interlocked with each other and to ensure that minimum on and off conduction requirements for the GTO's are met. The three gate drive modules in each inverter are fed from a common inverter power supply which has monitoring acting directly on the gate drives in the event of a failure. This is one of the few functions reported to rather than controlled by the microprocessor. The circuit has a potential short circuit failure mode if both thyristors in an arm are switched on together. It is therefore imperative to detect that one device is off before the other is switched on. The speed with which this must be done requires hardware implementation. It is convenient to do this within the gate drive module.

DEVICE COOLING

One of the design objectives was to minimise the space occupied by the inverter equipment. This has the added benefit of reduced stray inductance and improved electrical performance. In order to achieve this and to deal with the relatively high GTO losses a phase-change cooling system was designed. The principle of operation is depicted in Fig. 3.

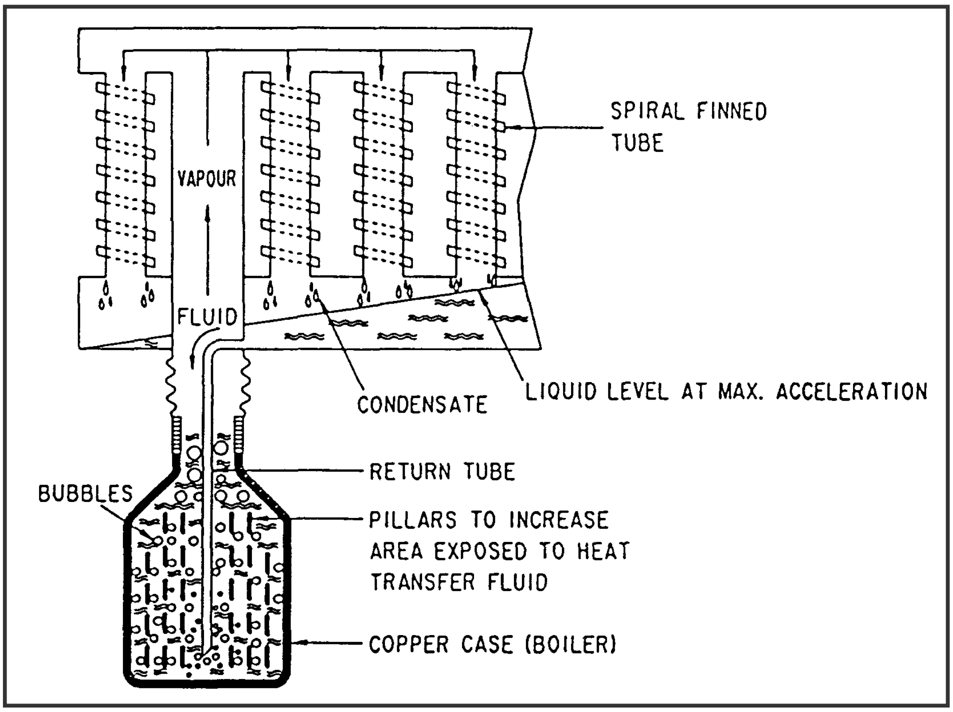

Fig. 3 CROSS SECTION OF ONE HALF OF A PHASE CHANGE COOLER ASSEMBLY

A hollow copper boiler unit is clamped to the GTO's in a stack, with a similar parallel stack of anti-parallel diodes. When operating the cooling liquid is evaporated and the vapour passes up into the radiator assembly. This is connected to the boiler via an insulating ceramic tube and a bellows to give flexibility. Two boilers are connected to the same heat exchanger with one boiler cooling the thyristor and the other cooling the diode, as shown in Fig. 3. This gives the best utilisation of the heat exchanger. The condensed vapour is returned via a pipe to the bottom of each boiler. The unit is designed so that there is no starvation of the returning liquid under acceleration forces. There are many liquids available with suitable electrical and thermodynamic properties, including pure fluorocarbons.

The resulting unit is sealed for life and maintenance of the semiconductors can be carried out relatively easily. The basic cooler module can be used for any semiconductor assembly, and may be adapted to suit differing power 1evels. The original design has been sized to be suitable for 500kW to1MW inverter ratings.

Overall the cooling system has proven to he about twice as efficient as a force cooled arrangement, whilst occupying less than half the space for the sane thermal dissipation.

EMU APPLICATION

The Class 457 EMU uses the technology described above. Operating as a 4 car unit it essentially consists of two, 2-car units, comprising a driving motored car and a trailer car. The two propulsion systems are identical but independent, and each one powers 4 motors. There are 2 inverters per equipment each driving two motors (Fig. 4).

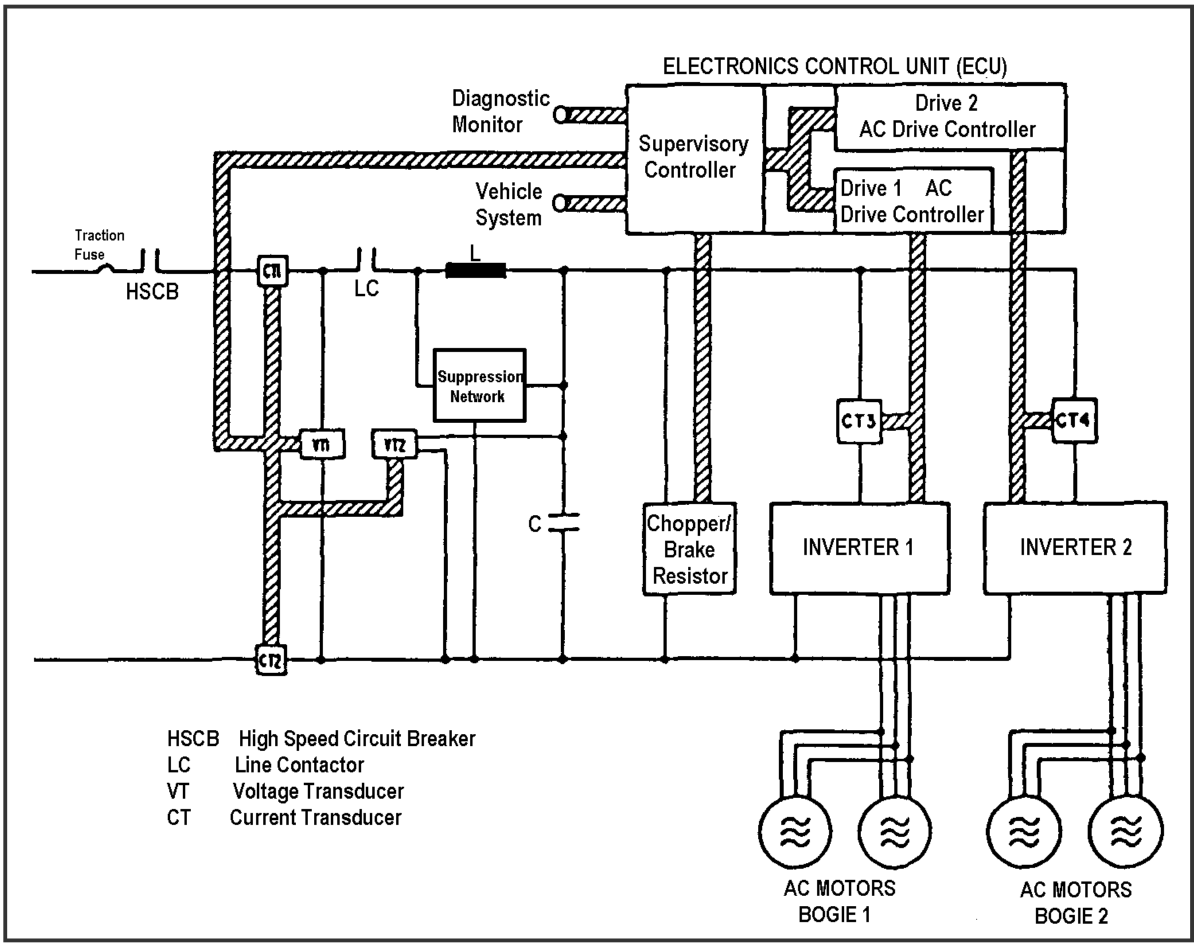

Fig. 4 BLOCK DIAGRAM OF EMU TRACTION CONFIGURATION

In order to give a reasonable ability to tolerate variations in wheel diameters between axles on the same bogie, the motors were designed with bronze bars to give increased rotor resistance. They are naturally ventilated and because of constraints on the bogie, axle hung. Each motor has a continuous rating of 165kW.

The equipment is fully regenerative and under loss of receptivity employs a short term rated rheostatic brake to provide a smooth transition into friction braking. The GTO chopper used to control this is constructed in a similar way to the inverter using the similar components.

Two options for brake blending were supplied. One was a conventional blend with friction on the motored car only, while the other was a scheme where the friction brakes (when required) were shared equally between the two cars. The regenerative brake provides most of the braking whilst the friction brake wear was equalised, so maintenance on both vehicles could be performed simultaneously. Either scheme is enabled via a switch in the supervisory software.

Similarly software control to vehicle performance providing different TE-speed characteristics is easily achieved and invoked by setting a simple constant table.

The line filter consists of a conventional low resistance LC filter and an additional low-loss suppression network. This prevents ringing on intermittent supplies, makes the system immune from shoe bounce, and improves stability. An optional active filter can be used to further reduce harmonic current levels at a specific frequency when a track based signalling system is particularly sensitive.

The unit successfully underwent an extensive test programme and became the first 3-phase inverter drive train in passenger service in the UK on BR. The sane basic components may be integrated into a single package tailored to suit any particular requirement. The operating power is raised to that needed for locomotive use by increasing the inverter supply voltage.

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