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AC DRIVE CONTROL WITH DYNAMICALLY RE-CONFIGURABLE ADAPTIVE CONTROLLER

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Abstract. Re-configurable systems are mainly used in configurable computing and embedded control systems. In this paper we present the concept of system reconfiguration and its possible application in vector control for an ac drive using the Triscend Configurable System-on-Chip (CSoC). The idea of a possible reconfiguration of the CSoC for embedded control is also introduced. The controller can be considered a state machine and adaptive control can be avoided. The changes in the control law due to reconfiguration may improve the performance of the controlled system. Some results of implementation and aspects concerning system resource management are also presented.

Keywords: Vector control, Drives, Adaptive control, System reconfiguration, Embedded control.

1. INTRODUCTION

There are several approaches defining re-configurable systems. „Re-configurable Computing technology is the ability to modify a computer system's hardware architecture in real time" [10]. Re-configurable computing is also often called „Custom" or „Adaptive". There was demonstrated significant potential for the acceleration of computing in general-purpose applications [2], [6], [7], [11] and [12].

Re-configurable systems are usually considered those computing platforms whose architecture is modified by the software to suit the application at hand. This means that within the application program a software routine exists, that downloads a digital design directly into the re-configurable space of the system. Most of Re-configurable Computing Systems are plug-in boards made for standard computers and they act as a Co-processor attached to the main micro-processing unit. The computing research community defined the re-configurable computing as one of very popular subjects.

Maciejowkski [5] introduced another approach to reconfigurable systems. According to his opinion the re-configurable systems are important when a major failure occurs. In the event of a failure at least three inter-related questions arise

1. Is it possible to control the plant to continue the original mission in safety conditions?
2. Is it possible to control the plant with reducing the specification of the original mission?
3. Is it possible to cancel the mission without incurring a disaster?

These questions occur primarily in safety critical systems/plants. Re-configuration is also possible if no failure occurs, but the changes in system parameters demand a much more effective control law.

This paper combines both approaches in trying to give a solution on how to implement a re-configurable embedded controller for an AC drive.

The following sections present the background of re-configuration. Then some particulars of vector control are highlighted, and finally implementation of a re-configurable embedded controller using the Triscend Configurable System-on-Chip (CSoC) is outlined

2. RECONFIGURATION BACKGROUND

Field Programmable Gate Arrays (FPGAs) are used for implementing of high-volume digital applications, for which no standard off-the-shelf solution exists.

A field-programmable gate array consists of *programmable logic cells*, containing combinatorial logic function units and registers, *programmable routing network*, *input and output cells*. The routing network connects the logic cells with each other and with the programmable I/O cells.

Most of FPGA chips can be reconfigured through the configuration memory space. This is composed of SRAM cells; intermixed on the chip with the logic cells and the routing network. The configuration bits stored in the SRAM cells are loaded during a configuration process from an external storage device.
The FPGA and its several configurations stored in external memory can be used as multifunctional hardware, with the on-chip changing functionality in reaction to the current demands. The configuration procedure can be a part of the power-on process of the FPGA or can be started externally

in any time during the system evolution by a microprocessor or another FPGA.

Computing devices make use of configurable elements in very different ways. The least demanding technique is to switch between functions on commands - the hardware equivalent of switching between one program and another.

Most of the applications on re-configurable hardware focus on the following areas:

- Custom computers. They are made of several FPGA chips with attached RAM memories. Typically, they use a host computer only for data management. Custom computers implement large applications in hardware. Examples: Splash, Teremac
- Re-configurable coprocessor boards. This class of FPGA-based boards covers smaller devices, which are used in close co-operation with a host computer. Example: Hades RC, Chameleon, and VCC's Re-configurable Processing Unit.
- Re-configurable processors. They are a combination of FPGA chips with CPU cores.

All above-mentioned boards need an external computing element to control and complete the reconfiguration. This is their main disadvantage.

Hauck outlined [2], [3] the future of re-configurable systems in form of a configurable system-on-chip, that contains all the elements for configurable applications and signal processing. The possible elements of the configurable system-on-chip are presented in Fig. 1. They are as follows: Microprocessor core, FPGA, DSP resources, RAM, special Interface Logic and Field Programmable Analogue Arrays.

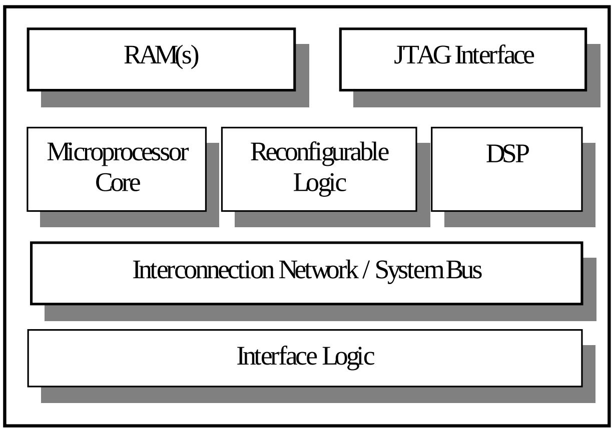

Fig. 1. Possible structure of a future Field Configurable System on a Chip

Triscend Inc announced in 1998 the registered Configurable System-on-Chip (CSoC) made for general purposes and containing most of embedded system's logic.
The basic elements included within this CSoC are shown in Fig. 2. They are:

- A silicon-efficient, industry-standard processor core, that provides the processing resources. If a standard micro-controller is implemented the dedicated peripherals are also included.
- On-chip memory capable to store both system code and data. A small, bootstrap ROM supports the system boot-up. Interfaces to external memory are provided.
- Programmable logic resources, that support custom defined peripherals and implementing fast algorithms.
- Test and control logic, that supports system reconfiguration (JTAG), clock signal generation, power-on reset and bus arbitration controls.
- Dedicated, high performance internal bus, that provides flexible connections between the processor and its peripherals, customised logic and external memory via the memory interface unit.

The Starter Kit has a 8051 microcontroller core, but the next generation of the CSoC will contain more powerful ARM-based cores.

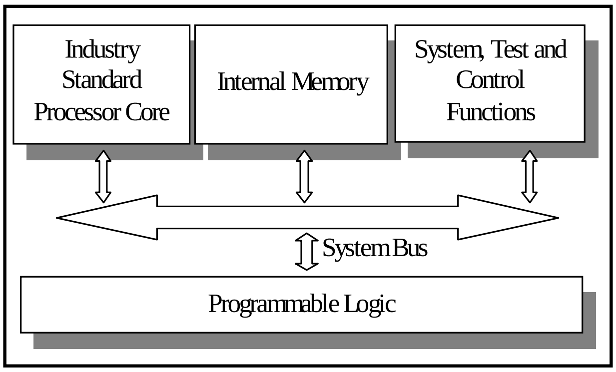

Fig. 2. Structure of the Triscend CSoC

The Configurable System on a Chip solution with its flexible structure can implement the desired re-configurable controller described by [5] under the following conditions:

1. External memory is needed to store the several configurations (Configuration Store).
2. Either software or hardware has to be capable to start a reconfiguration on need. In the case of Triscend's CSoC, external configuration generator has to be implemented. A software solution is also possible; i.e. a system reset is started by the implemented application and is executed by the external reset generator (Configuration Starter).
3. The evolution of the system must be predictable in order to pre-compute the possible configuration.
4. The system control states have to be quantified and finite; that is a condition imposed by the finite capacity of available external memory.
5. The existence of 'high-fidelity' models and effective approximation-identification algorithms for multivariable systems. This condition was defined and imposed in [5]).

3. VECTOR CONTROL ISSUES

Most of electrical motor applications use asynchronous motors. To control induction motors the field oriented control method achieves the best dynamic behaviour. The principle of the field-oriented control is shown in Fig. 3.

Based on Park's direct and reverse transformations the AC motor can be controlled like a separately exited DC machine, whereby the direct (d) path is representing the flux building component and the quadrate (q) path sets the electrical torque. Best results are obtained when the magnetising current i_{mr} is kept constant, which is direct proportional to the rotor flux Ψ_r under the assumption that the main inductance L_h is constant [4].

The following equations describe the mathematical model of the AC motor in d-q co-ordinates:

$$\begin{bmatrix} u_{sd} \\ u_{sq} \end{bmatrix} = R_s \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} + \sigma L_s \frac{d}{dt} \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} - \sigma L_s \omega_{mr} \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} + (1-\sigma) L_s \frac{d}{dt} \begin{bmatrix} i_{mr} \\ 0 \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} = \begin{bmatrix} 1 \\ (\omega_{mr} - \omega)\tau_r \end{bmatrix} i_{mr} + \tau_r \frac{d}{dt} \begin{bmatrix} i_{mr} \\ 0 \end{bmatrix} \quad (2)$$

$$m_e = \frac{3}{2} z_p (1-\sigma) L_S i_{mr} i_{sq} \quad (3)$$

$$m_e - m_r = \frac{J}{z_p} \frac{d\omega}{dt} \quad (4)$$

Based on the above mathematical model, a flux model was derived and a controller was developed (Fig. 4.) [4].

4. THE RE-CONFIGURABLE CONTROLLER

In the present application study, the process to be controlled is a voltage source inverter fed ac motor drive. The CSoC is the hardware support for the controller. The necessity of re-configuration is based upon the practical observation that the performance of a vector control drive depends primarily on the flux identification method, on the load characteristics (dynamic and/or static) and on the range of the speed.

It is known that the rotor flux oriented vector control is simpler to implement and therefore, widely used [8]. One drawback of this method is the low efficiency at low ranges of speed. For lower speed range, the stator flux oriented vector control is preferred. Unfortunately, the above mentioned controllers have different structure but each of them can be successfully implemented in the CSoC.

The main idea introduced in this paper consists of the application of the re-configurable controller concept for the case of implementing different controllers for the same controlled process. The CSoC implementing at one moment one controller structure can be used not only to implement that controller, but also to switch to another control law.
Each controller structure can be seen as a distinct state of a state machine (Fig. 3.). Each state represents a different hardware configuration of the CSoC.

The first attempt was to implement two controller structures into two different configuration states (S1, S2) of the CSoC. Transition from one state to the other can be determined by the state parameters of the controlled system. If a transition condition occurs, i.e. the motor speed reference transits a limit value, the need for reconfiguration is fulfilled and the controller generates the self re-configuration process. In principle, the state machine can be extended to implement other control schemes, too.

The main problem that appears consists of how can be managed the drive during the re-configuration process. Our future work will concentrate upon this item.

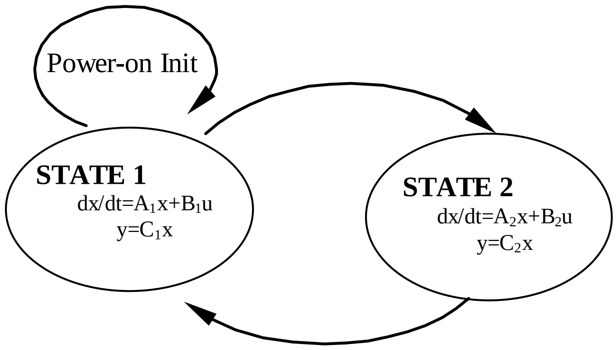

Fig. 3. The state transition graph of the re-configurable controller

5. CONCLUSIONS

This paper presented a possible implementation of the vector control for an AC drive using the CSoC. The idea of a possible re-configuration for control was introduced. The changes in control law due to re-configuration may improve the performances of the controlled system and adaptive control can be avoided.

The implemented control structure for vector control is CSL (Configurable System Logic) resource consuming. As example, Fig. 5. presents the CSL resource allocated when Park's transformation matrix multiplication is only implemented. The result is 33% that seems to be a very high rate. This could be considered due to the apparently low capacity of the TE520S40 chip that the Starter Kit is equipped.

One solution to the problem of available resources is to improve the algorithm implementation. Further research work has this perspective. Another solution could be using parallel architectures.

Another problem that seems to appear consists of how can be managed the drive during the re-configuration process. The future work will concentrate upon this item, too.

6. ACKNOWLEDGMENT

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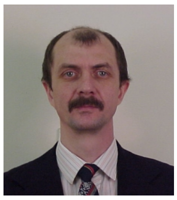

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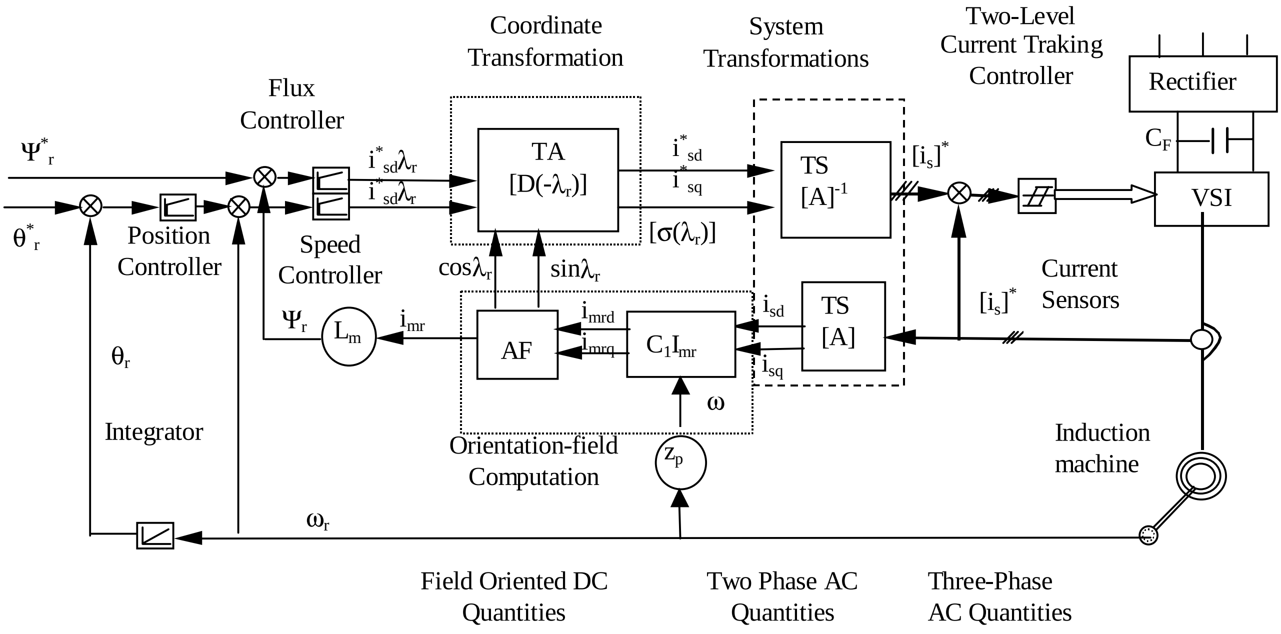

Fig. 4. State 1: Vector control system for voltage-source inverter-fed induction machine

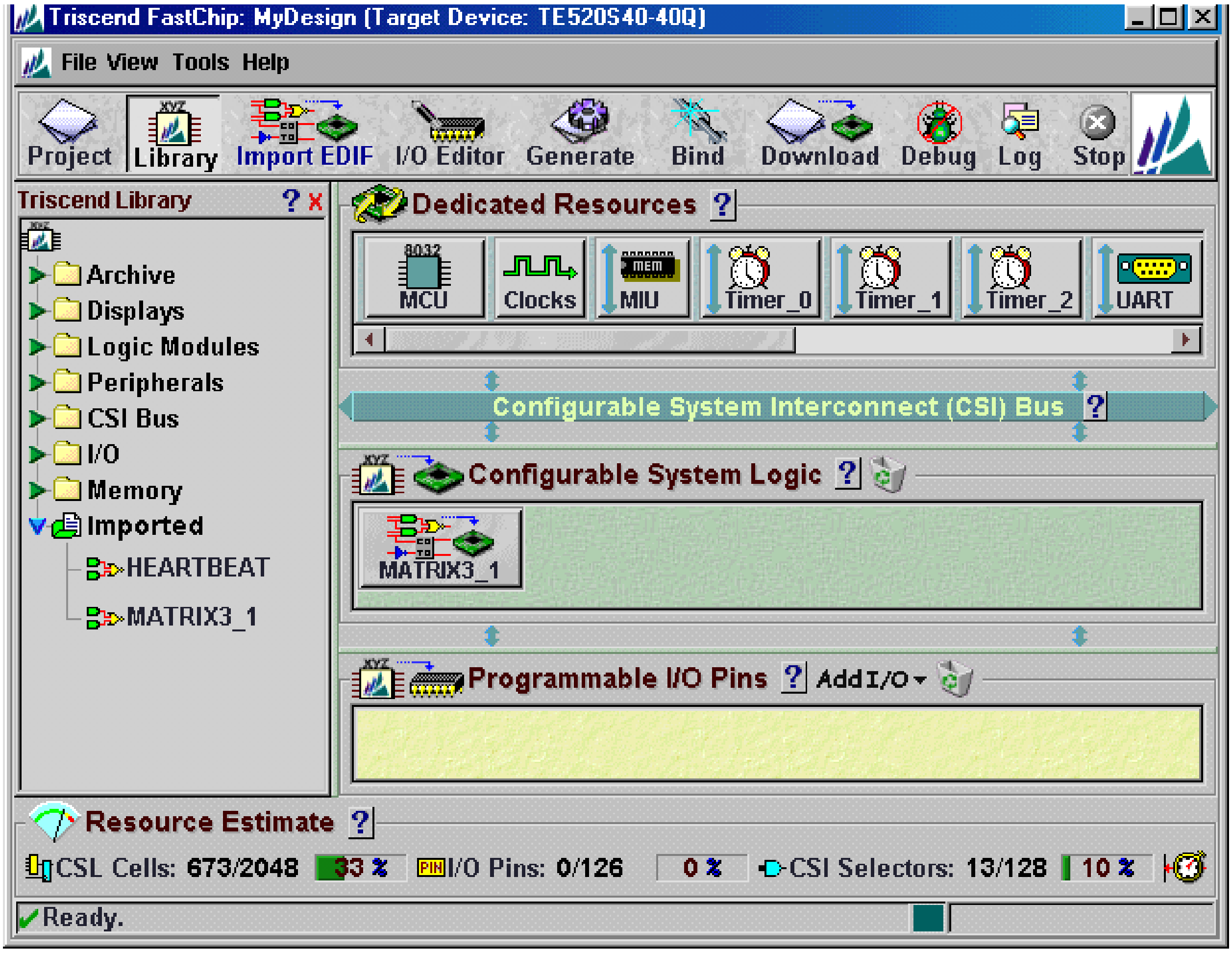

Fig. 5. 33% of Resources used in the CSL implementing the matrix multiplication