Synthesis of Reconfigurable Vector Control of Tandem Converter Fed Induction Machine Drive

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Abstract – **The paper deals with reconfiguration of field-oriented vector control structures for the tandem frequency converter fed induction motor drives. The tandem converter is composed of two parallel connected, different type DC-link converters. Rotor and stator oriented vector control schemes using different modulation techniques are discussed. The drive is able to run also with partial-failed tandem converter, if the control strategy is reconfigured to the corresponding operating mode. The hardware implementation of reconfigurable control structure is analysed. Matlab-Simulink simulation was performed.**

I. INTRODUCTION

Accordingly to the definition the reconfigurable systems are 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 reconfigurable space of the system [1], [2].

Reconfiguration of a control system may be necessary when a major failure occurs in the controlled plant or the changes in the control system variables demand much more effective control law and no adaptive control facilities are implemented [5], [20]. The need for reconfiguration is more evident if the controlled plant is of considerable importance (vital functions, high power, etc).

An alternative solution for medium- and high-power AC drives is the "tandem" static frequency converter (SFC) fed induction motor. This configuration is a hybrid SFC, which combines the advantages of two, parallel working, different types and different power ranges DC-link converters. A large power Current Source Inverter (CSI), operating in Pulse Amplitude Modulation (PAM) converts the active power, and a small power Voltage Source Inverter (VSI) working in Pulse Width Modulation (PWM) and supplies the reactive power required for improving the quality of the motor currents [7], [8].

To obtain the best dynamic behaviour the control of the tandem-converter-fed induction motor can be achieved using conventional vector-control structures [8], [10].

Let suppose one of component converter (VSI or CSI) fails. This means, the control structure loses its tandem character and the control structure will work with only one inverter. Under these new working conditions, the control structure previously applied to the tandem converter is not more efficient. To keep the drive working the control structure need to be reconfigured corresponding to the working inverter character [11], [12].

II. RECONFIGURATION OF TANDEM CONVERTER FED VECTOR CONTROL SYSTEM

Different working condition of the tandem fed drive system may be considered as different states of a logic state machine. The transition between these states is accomplished via reconfiguration (Fig. 1). Note that the main working control structure is the tandem converter (*STATE* 1), and the need for reconfiguration is motivated with the fail of one of the inverters. The tandem converter needs different control strategies depending on the character of the working component-converter and on the modulation procedure used for the VSI [6], [15], [17], [19].

A. Rotor–field orientation with Space Vector Modulation

The tandem fed drive system (Fig.2) works using rotor-field orientation due to the perpendicularity of the rotor-current and rotor-flux space phasor. The tandem operation mode corresponds to *STATE* 1 and due to the fact the VSI is working, the motor should be controlled in voltage.

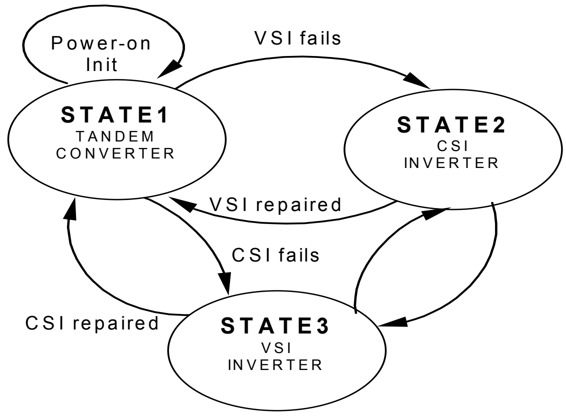

Fig. 1. The state transition graph of the tandem converter system.

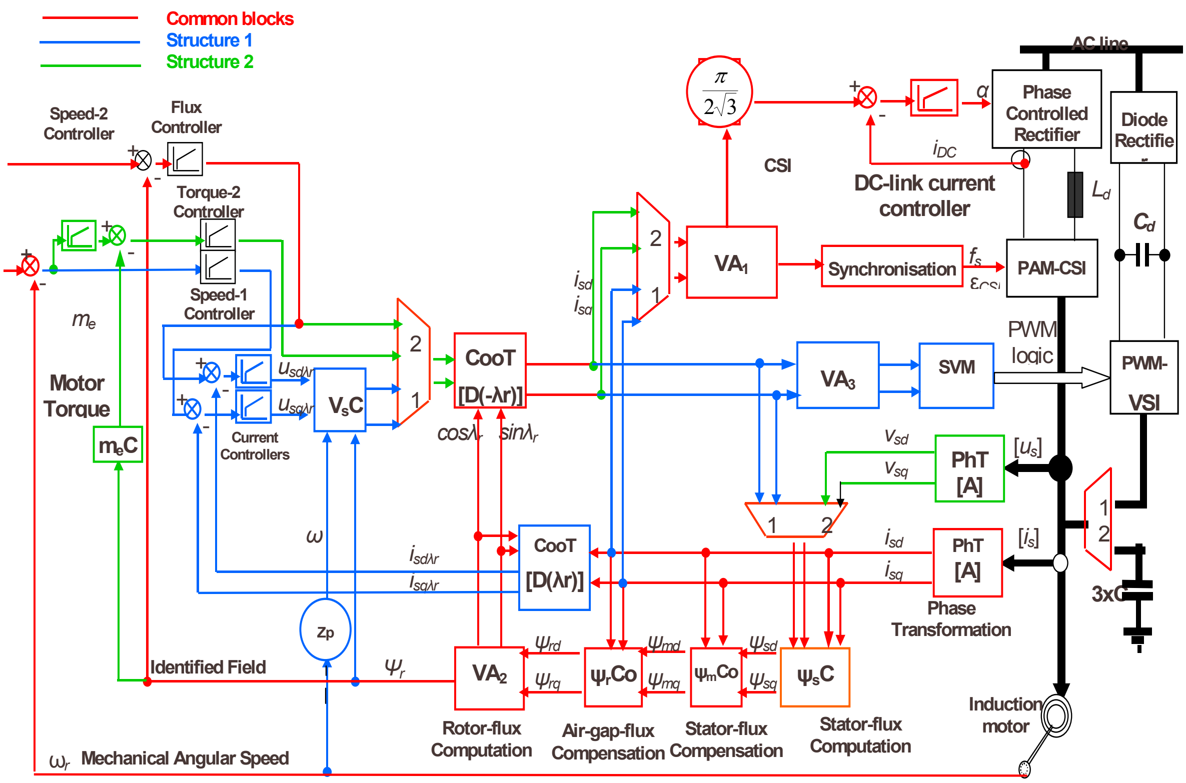

Fig.2. Reconfigurable Rotor-Field Oriented Vector Control System with Space Vector Modulation (SVM) for the tandem converter-fed induction motor.

The field identification is made by integration of the stator-voltage equations (using computation block ΨsC). The stator-flux d-q components are compensated in block Ψ_mCo and Ψ_rCo in order to obtain - first the air gap field and then - the orientation one. The identified rotor-flux components are analysed in block VA_2, which gives the field magnitude Ψ_r and its position λ_r.

The current reference variables $i_{sd\lambda s}$ and $i_{sq\lambda s}$ obtained from the flux and speed controllers will generate the field-oriented voltage reference values corresponding to Ohm's law. I.e. $u_{sd\lambda r}$ and $u_{sq\lambda r}$ and using the computation block V_sC the cross-effect is taken into account and results the field-oriented control variables of the motor terminal voltage $v_{sd\lambda r}$ and $v_{sq\lambda r}$, according to the equations, as follows:

$$v_{sd\lambda r} = u_{sd\lambda r} + (-\omega_{\lambda r}\sigma L_s i_{sq\lambda r} + \frac{1}{1+\sigma_r}\frac{\mathrm{d}\Psi_r}{\mathrm{d}t}); \qquad (1)$$

$$v_{sq\lambda r} = u_{sq\lambda r} + (+\omega_{\lambda r}\sigma L_s i_{sd\lambda r} + \frac{1}{1+\sigma_r}\omega_{\lambda r}\Psi_r); \qquad (2)$$

The electromagnetic cross effect is represented by the expressions in brackets.

Because the VSI is operating with SVM, it needs polar control variables, corresponding to the reference stator-voltage space-phasor, i.e. its module v_s^{Ref} and position γ_s^{Ref}, which are obtained from a vector analyser VA_3.

If the VSI fails, it is decoupled from the motor terminals, and there will be connected three filtering capacitors to avoid voltage spikes. In this case, the CSI will supply alone the motor represented by *STATE* 2 in Fig. 1, and the inverter currents are synchronized with respect to the control variables of the stator-current d-q components. This control structure is much simpler than that of *STATE* 1 due to the fact, the CSI is directly controlled with current variables, and there are no more needed current controllers and cross-effect computation. The rotor-field orientation is well suitable because the computation of the control variables, in such a case is not affected by the motor parameters .

The field identification is made in the same way, but it needs also reconfiguration because in *STATE* 2 the stator voltage is measurable directly on the motor terminals (due to the PAM operation mode of the CSI), instead to be computed, as was before in *STATE* 1, during the PWM operation mode.

B. Stator–field orientation with Space Vector Modulation

Fig. 3 presents the implementation principle of the stator-field oriented tandem converter fed induction motor drive system. The identification of the orientation-flux is simplified with respect to the before presented rotor field orientation scheme, because no compensation is needed. The stator flux is computed in block Ψ_sC also by integration of voltage equations. The module Ψ_s and the rotation angle λ_s of the orientation stator-flux phasor are obtained in the vector analyser VA_2.

To improve the system stability in stator-field orientation the torque control is required.

In situation of failed VSI, the motor will be controlled exclusively in current directly taking into account the reference current variables, as is shown in Fig. , path 2 of the multiplexers. Consequently, the structure of the control system needs reconfiguration.

The current synchronisation of the alone working CSI was realized in the same manner like *STATE 1*, but is computed from the reference values instead of the actual

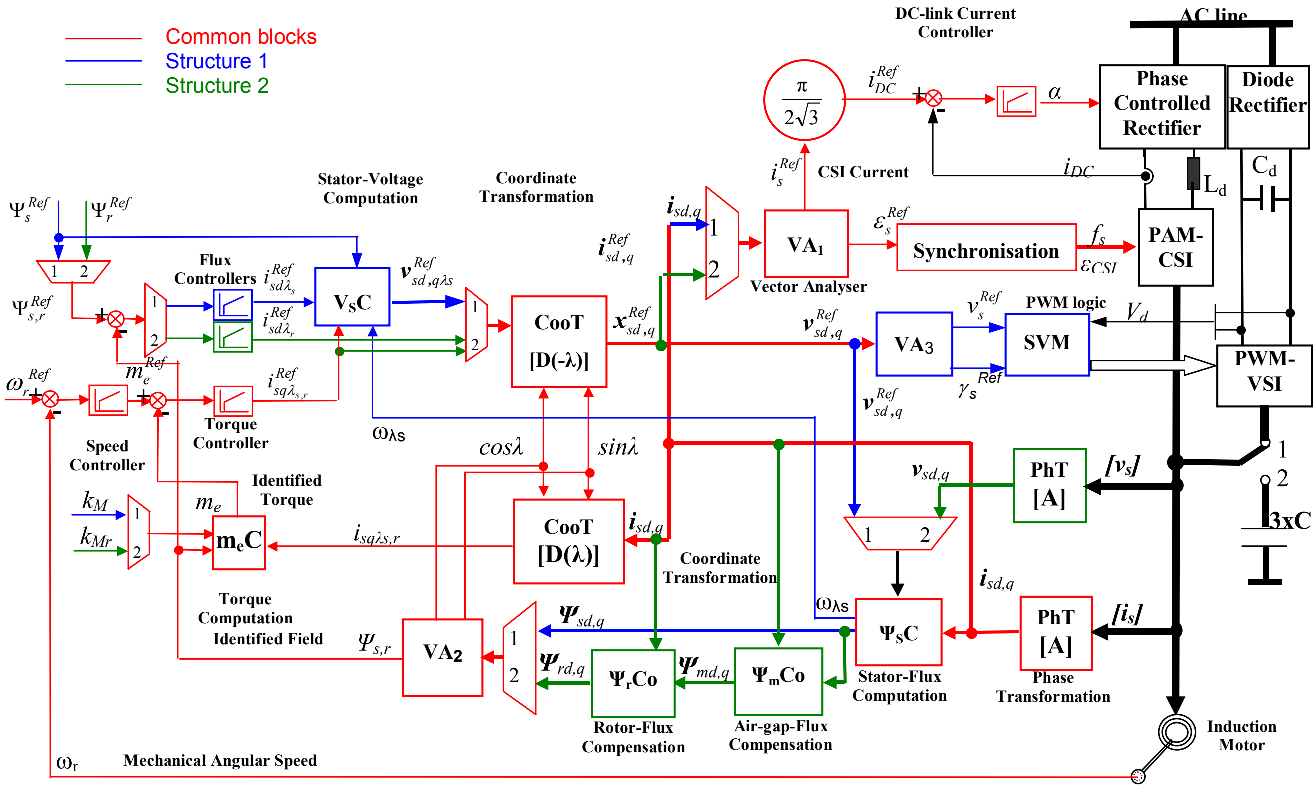

Fig. 3. Vector control system with reconfiguration of stator-field orientation and space vector modulation (SVM) for the tandem converter-fed induction motor.

ones of the stator currents. The field identification in the first step is made in the same way, by integration of the stator-voltage equations (using computation block Ψ_sC), which gives the stator-flux natural d-q components.

The flux identification (Ψ_s, Ψ_m, Ψ_r) modules are same for both structures. The CooT[D(-λ)] module is common, but while in *STATE 1* is computing the voltage reference values ($v_{sd,q}^{Ref}$), after reconfiguration will compute the current reference values ($i_{sd,q}^{Ref}$). The structure is most sensitive to the controller reconfiguration as this part of the control scheme needs major reconfiguration. While in the tandem mode the system is working with the current controllers and the cross effect computation (V_sC), in CSI configuration mode it is introduced a second speed-controller together with a torque controller.

C. Rotor–field orientation with Current Feedback Modulation

Applying to the VSI current-controlled-PWM, in manner of the "bang-bang" converter, the tandem-converter-fed motor will be controlled in fact in current. Constant switching frequency is obtained using synchronized on-off switching controllers. In Fig. 4, the induction motor operates supplied from the both converters in tandem mode (corresponding to position 1 of the multiplexers). Supposing a fail of the VSI the control structure has to be adapted to the new working condition, i.e. running supplied only by the CSI (position 2 of the multiplexers). Due to its simplicity, both operating modes use rotor-field orientation. In the tandem-fed mode, the VSI operates with current feedback loops. Because of the difficulties encountered by direct measurement of the modulated-voltage waves, the stator voltage is identified in block V_sId using the measured DC-link voltage and the state of inverter switches according to the PWM logic and taking into account the voltage losses on semiconductor devices, too. Based on the stator-voltage and current components transformed in d-q reference frame, the block Ψ_sC integrates the natural stator-voltage equations yielding at its outputs the stator-flux d-q components. If only the CSI is working the stator voltages used in orientation flux identification are direct measurable. Because the parameters are different the controllers need reconfiguration, too.

III. HARDWARE FOR RECONFIGURATION

Most used hardware support for practical implementation of vector control probable is the Digital Signal Processor (DSP). Their intensively optimised architecture and the integration of peripheral units (PWM, ADC, Timers), provides the highest possible performance for a given speed and algorithm critical applications like vector controlled drives, but the reconfiguration of the DSP based control structure it is not possible.

Due to the technological advancements in Field Programmable Gate Arrays (FPGAs), they offer the design flexibility and adaptability with optimal device utilization. Data can be processed taking advantage of single chip paralleled structures and arithmetic algorithms to exceed the performance of a single general-purpose DSP device, increasing the data bandwidth and throughput as much as several order of magnitudes greater in FPGAs than that

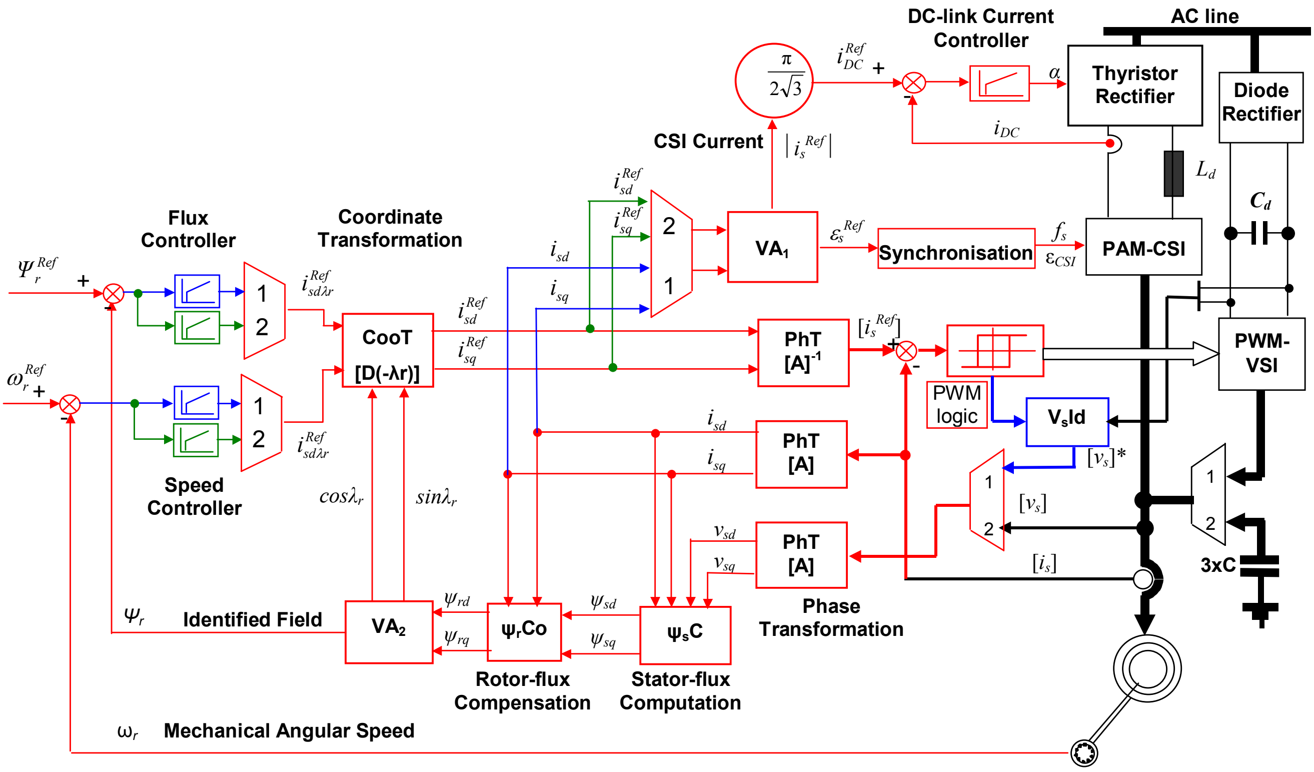

Fig. 4. Reconfigurable rotor-field oriented vector control system with current feedback modulation for the tandem converter-fed induction motor.

possible ready made DSP solutions.

Configurable System on a Chip (CSOC) integrates on a single device, a performance-enhanced embedded microcontroller or microprocessor or DSP core, a large block of SRAM, a high-speed dedicated system bus, and configurable logic, connected to the processor and system bus. The CSOC allows in a single chip to process data in either hardware or software algorithm, which results in a faster processing time [9].

IV. SIMULATION RESULTS

In all the three possible reconfiguration variants the simulations were performed in similar conditions in MATLAB-Simulink environment. The motor data are: 5.5 kW, 50 Hz, 220 V r.m.s., 14 A r.m.s., 720 rpm, cosφ = 0.735 and 4 pole-pairs. The reference values of the fluxes were considered the calculated rated peak values (i.e. the module of the space phasors defined with 2/3 coefficient). They are Ψ_r=0.8387Wb and Ψ_s= 0.9684Wb. The motor rated electromagnetic torque was also calculated m_e = 81.05N.m.The motor was started controlled by the tandem inverter and after some time (usually 0.5s after start) the control structure was reconfigured due to the failed VSI.

The simulations were concentrated on the moment of the reconfiguration and what are the effects on the motor variables if the control structure is reconfigured. The research was not extended to the fault detection, which is not the subject of this paper. We presumed that the moment when the VSI fail could be detected in a way (for example detecting the equality of three voltages $u_{sa} = u_{sb} = u_{sc} = 0$ at the same time). The results are presented on Fig. 5….Fig.10.

VI. CONCLUSION

The goals of reconfiguration of tandem converter fed vector control drive systems are:

- to maintain the operation of the drive even in case of fail.
- to improve the working condition.

Vector control systems for AC drives are characterised by high dynamical changes, and yet it is technologically impossible to compile the next configuration in run-time for such systems. The reconfiguration is applicable only if the next configuration is known at compile time, while the duration of the actual configuration is known or may be unpredictable. The reconfiguration, due to the changes in the hardware of control structure, introduces perturbations in every observed parameter of the drive, influencing also its dynamic performance. CSOC and FPGA implementations are possible. The development of reconfigurable computing devices is promising for the reconfigurable control of AC drives leading to the decreasing of the sampling period.

IV. ACKNOWLEDGMENT

The “Tandem Inverter” was subject of a research project carried out at the Institute of Energy Technology, Aalborg University, Denmark. Thanks to Prof. A. Trzynadlowski from Nevada University, Reno, USA for the collaboration and to Prof. F. Blaabjerg from the Aalborg University and to the Danfoss Drive A/S, Denmark for their generous support. The authors are grateful to Xilinx Inc. and *Triscend Inc*. and many thanks for *Mr. Chris Balough* for donations, which made possible the research on some aspects of reconfigurable vector control framework.

Rotor-field oriented vector control system with space vector modulation:

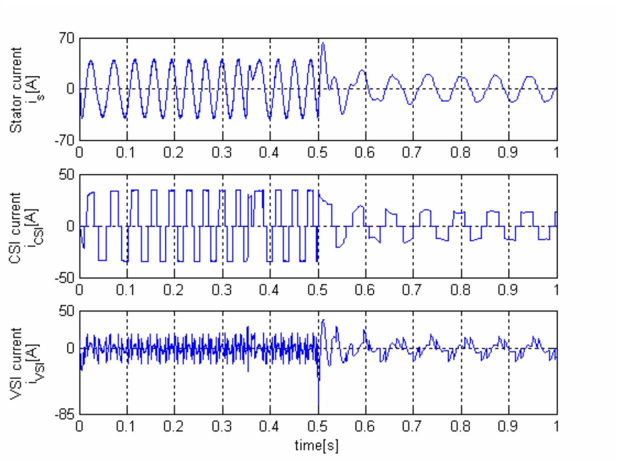

Fig. 5. Current waveforms before and after reconfiguration.

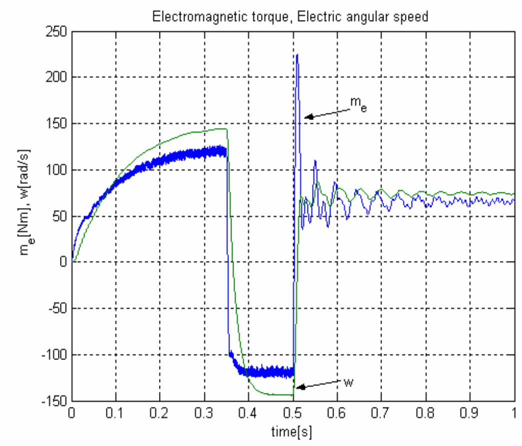

Fig. 6. Electromagnetic torque, electric angular speed before and after reconfiguration.

Stator-field oriented vector control system with space vector modulation:

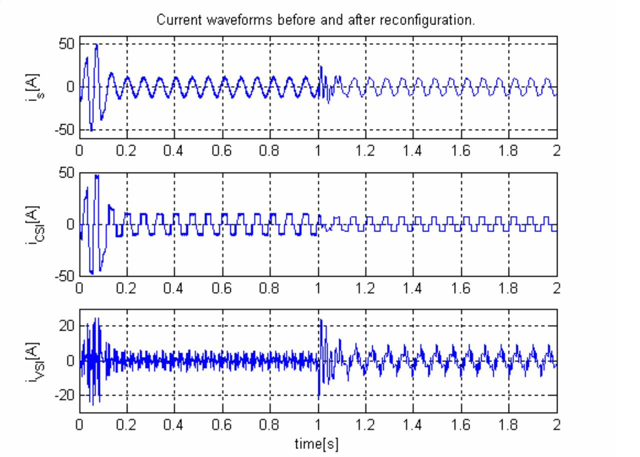

Fig. 7e Current waveforms before and after reconfiguration.

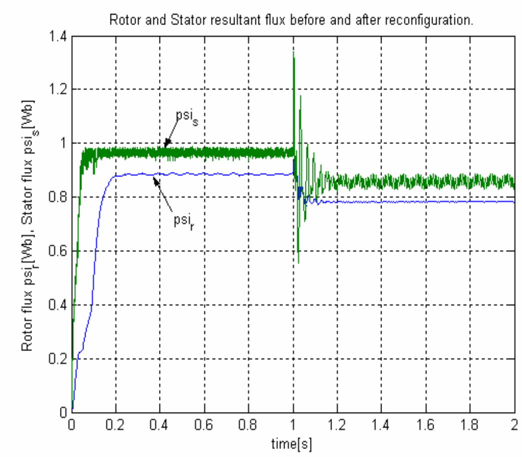

Fig. 8. Electromagnetic torque, electric angular speed before and after reconfiguration.

Reconfigurable rotor-field oriented vector control system with current feedback modulation:

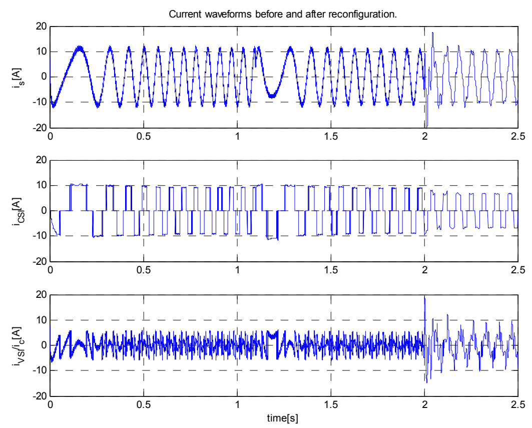

Fig. 9. Current waveforms before and after reconfiguration.

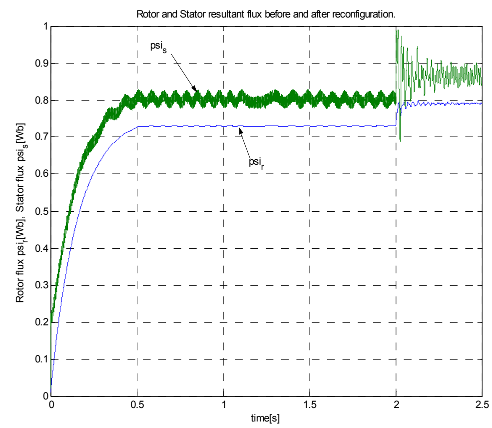

Fig. 10. Electromagnetic torque, electric angular speed before and after reconfiguration.

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