A&QT-R 2002 (THETA 13)
2002 IEEE-TTTC-International Conference on Automation, Quality and Testing, Robotics
May 23-25, 2002, Cluj-Napoca, Romania

RECONFIGURABLE CONTROL OF TANDEM-CONVERTER-FED INDUCTION MOTOR DRIVE

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Abstract: The paper focuses on the vector control systems of the induction motor supplied from the tandem (hybrid) static-frequency converter. Reconfigurable control structure ensures different strategies for operating modes with non-failed and partial-failed converter. Simulation results are presented for both basic topologies of the field-oriented control system. Problems related to hardware and software implementation of the transition from a control structure to another are discussed.

Key words: DC-link frequency converter, induction motor, vector control, field-orientation principle, reconfiguration.

1. INTRODUCTION

The dynamic behaviour of the induction machines is substantially improved by the field-orientation principle based vector-control system. The control structures of the drives is determined also by the type of the Static Frequency Converter (SFC) used to supply the vector-controlled machine (especially it is depending on its current- or voltage-source character) [1], [13].

The "*tandem*" configuration was proposed as a new solution of the SFC for medium- and high-power AC drives [2], [3]. It is a hybrid SFC, which combines the advantages of two component DC-link converters, which are of different type and different power range, and they are working in parallel arrangement. The control of the tandem-converter-fed induction motor can be achieved using conventional vector-control structures. If one of the component SFCs fails, in order to continue the drive its mission, the structure of the motor control system should be changed depending on the actual working component SFC. Reconfigurable structure allows adapting the control system - implemented on Field Programmable Gate Arrays (FPGA) - to the actual operating situations.

2. OPERATION PRINCIPLE OF THE TANDEM CONVERTER

The larger one of the component SFCs (Fig.1.) contains a conventional Current-Source Inverter (CSI) operating with 120° current wave-forms controlled by Pulse-Amplitude Modulation (PAM) and it converts the most part of the motor feeding energy. The smaller component SFC involves a well-known Voltage-Source Inverter (VSI) controlled by Pulse-Width Modulation (PWM) and it supplies the reactive power required to improve the quality of the motor currents in order to compensate them in sine-wave form. Consequently, the current i_s in each stator phase (*a*, *b* or *c*) will be given by the two parallel working inverters, i.e. by the CSI and the VSI, as follows:

$$i_s = i_{CSI} + i_{VSI} \qquad (1)$$

In this way it is no more necessary to apply PWM procedure to control the whole energy, because a large value of the it is transferred through the PAM-CSI, operating with reduced number of commutation. In comparison with an equivalent PWM-VSI, the tandem converter switching losses will be considerable reduced [2], [3], [4].

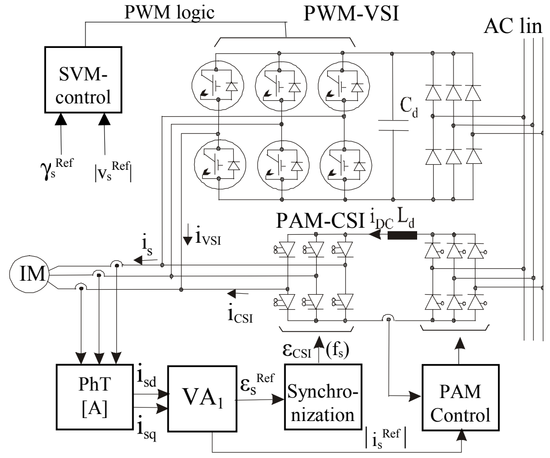

Fig. 1. Tandem converter topology.

Due to the voltage-source character of the VSI, the motor absorbs freely its stator currents. A part of this current will be injected by the CSI. That means in tandem-operation mode the CSI needs a rigorous synchronization with respect to the motor currents. The synchronization circuitry ensures the desired magnitude of injected current, i.e. the fundamental has to be equal with that of the stator-current in each phase of the motor. The synchronization in time of the CSI currents with respect to the stator ones is made by means of the switching moments ε_{CSI} (i.e. the electrical angle of the stator-current space phasor position) of the CSI currents with respect to the actual stator-current. The switching frequency f_s is resulting also inherently. The position of of the CSI-current phasor ε_{CSI} has to be synchronized with the reference value ε_s^{Ref}. The synchronization in amplitude is realized by means of the DC-link current i_{DC}, with respect to the amplitude of the actual stator-current vector $\underline{i}_s$.

3. VECTOR CONTROL OF INDUCTION MOTOR IN TANDEM-FED MODE

The induction motor drive system presented in Fig. 2., due its reconfigurable control, is able to work supplied by the tandem converter (corresponding to position 1 of the multiplexers) or supplied only by the CSI (position 2 of the multiplexers).

In tandem-fed mode, the motor is controlled in voltage. In this case stator-field orientation is proposed, which simplifies the cross-effect computation. The current reference variables $i_{sd\lambda s}$ and $i_{sq\lambda s}$ obtained from the flux and torque controllers will generate the field-oriented voltage reference values $v_{sd\lambda r}$ and $v_{sq\lambda r}$ using the computation block V_sC, as follows:

$$\mathrm{v}_{sd\lambda r} = u_{sd\lambda r} + (-\omega_{\lambda r}\sigma L_s i_{sq\lambda r} + \frac{1}{1+\sigma_r}\frac{d\Psi_r}{dt}) \qquad (2)$$

$$\mathrm{v}_{sq\lambda r} = u_{sq\lambda r} + (+\omega_{\lambda r}\sigma L_s i_{sd\lambda r} + \frac{1}{1+\sigma_r}\omega_{\lambda r}\Psi_r) \qquad (3)$$

Because the VSI is operating with Space-Vector Modulation (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. Due to the stator-flux orientation, this scheme also offers the simplest field identification, based on the integration of the stator-voltage equation. In CSI-fed mode the VSI will be replaced

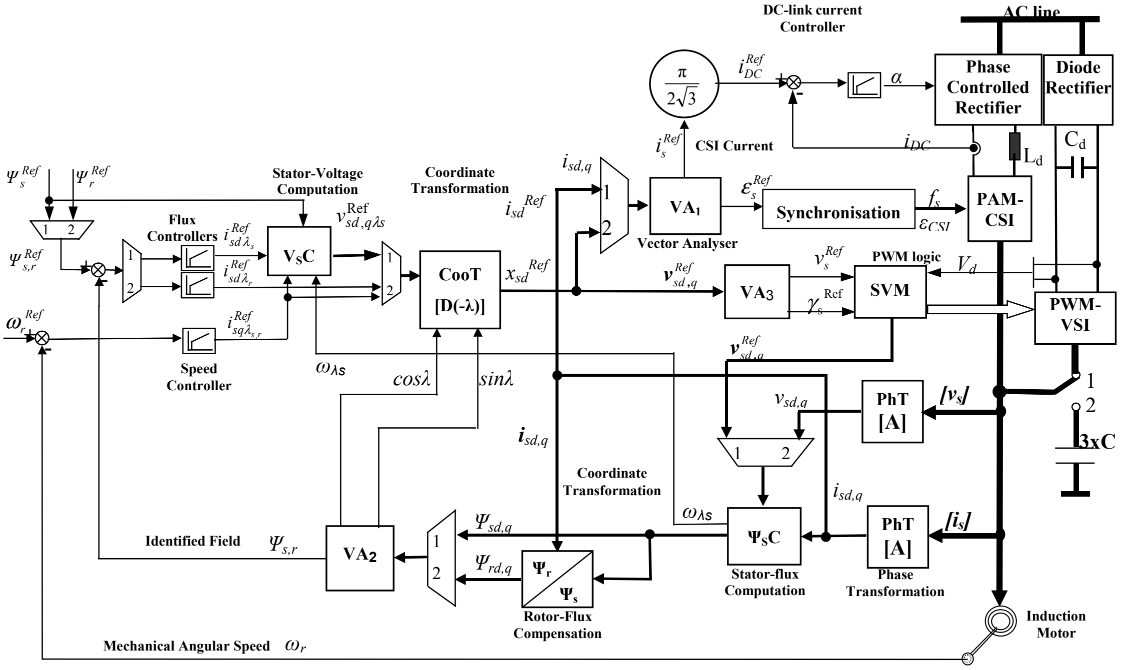

Fig. 2. Reconfigurable control system for the tandem converter-fed induction motor.

by 3 current-filtering capacitors, and due to the current-source character of the inverter the control structure is reconfigured for rotor-flux orientation. The field identification used before in tandem-fed mode has to be completed with a block for computation Ψ_s to Ψ_r compensation blocks in order to obtain the air-gap- and then the orientation field. In this case due to the lack of PWM procedure the stator voltage is directly measurable, it is no need for computing of them [10].

4. RECONFIGURATION OF THE CONTROL SCHEME

The reconfigurable computing technology means the ability to modify in real time the hardware architecture of a computing system. In case of AC-drive systems the same hardware support (which implements one control structure) can be used by reconfiguration to switch to another control scheme. Each structure can be seen as a distinct state of a logic state machine, as it is represented in Fig. 3 [9], [11]. The transitions from one logic state, i.e. one control-system structure (i.e. from one hardware configuration), can be determined by the value of the state variables of the controlled system.

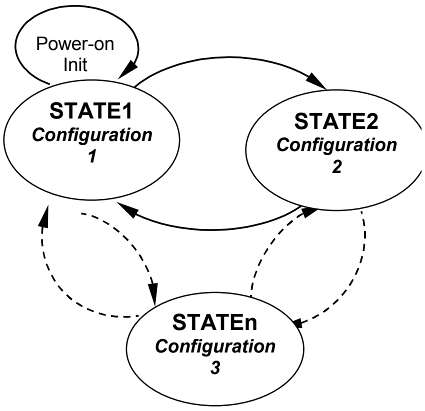

Fig. 3. State machine with different vector-control structures in each state.

The implementation of the control scheme in *Configurable System On a Chip* (CSOC) using distinct modules may results in low or insufficient hardware resources of the CSOC *Configurable System Logic* (CSL) cells. Implementation in FPGA overcomes this draw back. A simultaneous use of both is imaginable, too. It is possible to develop a module library, which allows a fast development process and prototyping [7], [5], [11].

5. SIMULATION RESULTS

The problem related to the simulation of the reconfigurable structures is the lack of the tools, which can simulate the reconfiguration process. A way out represents the simulation of both structures and then comparison of the obtained results. The simulation was performed in MATLAB Simulink environment. The induction motor rated data are: 5.5kW, 50Hz, 220V$_{r.m.s.}$, 14A$_{r.m.s.}$, 4% slip and 4 pole-pairs.

A. Stator-flux orientation using voltage PWM-VSI

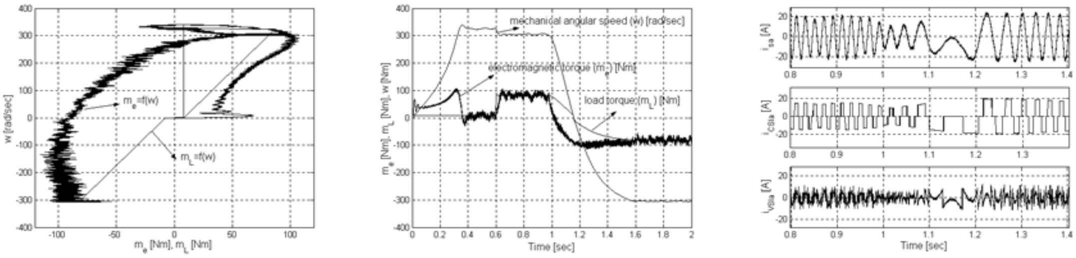

Fig. 4. Mechanical characteristics; motor torque, load torque and rotor angular speed versus time; motor and tandem converter currents.

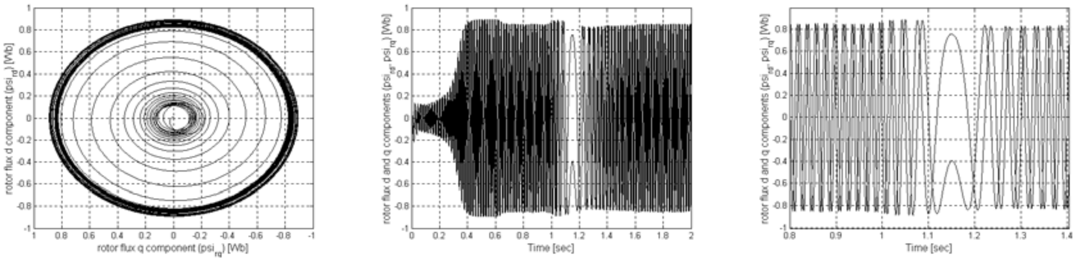

Fig. 5. Rotor-flux space-phasor trajectory, its d-q components versus time - starting and reversing detail diagrams.

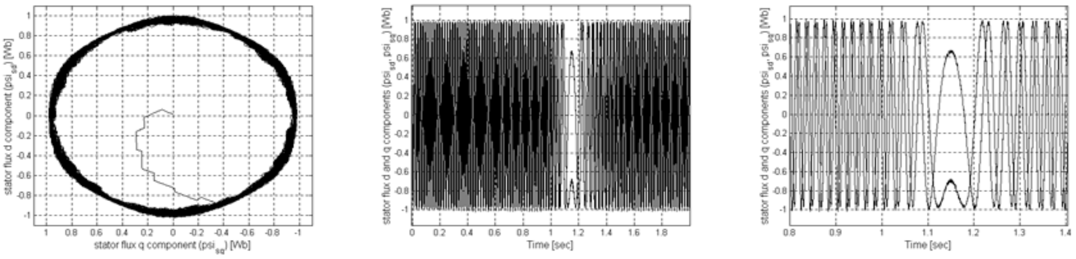

Fig. 6. Stator-flux space-phasor trajectory, its d-q components versus time - starting and reversing detail diagrams.

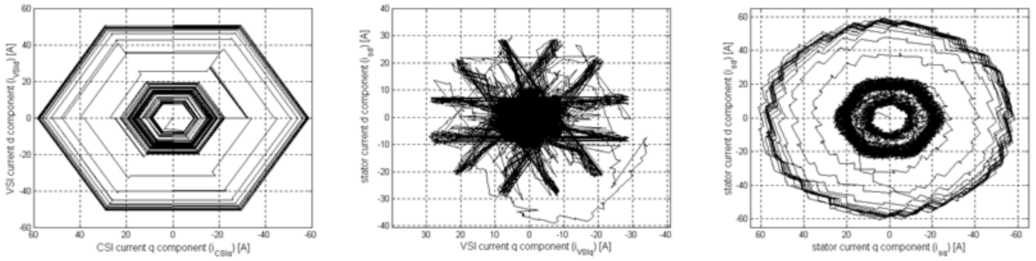

Fig. 7. Space-phasor trajectories of the CSI currents, VSI currents and stator currents.

B. Rotor-flux orientation using current-controlled PWM-VSI.

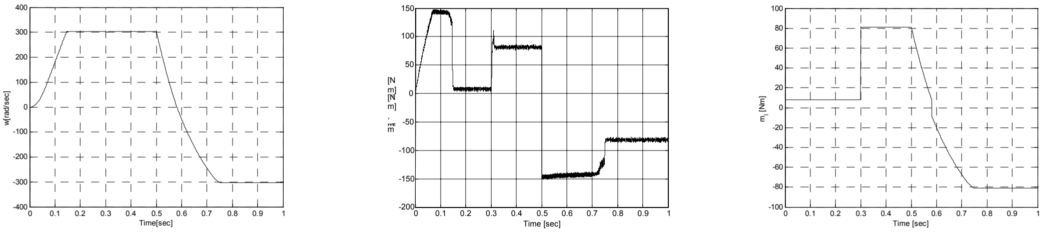

Fig. 8. Rotor angular speed, motor electromagnetic torque and load torque versus time.

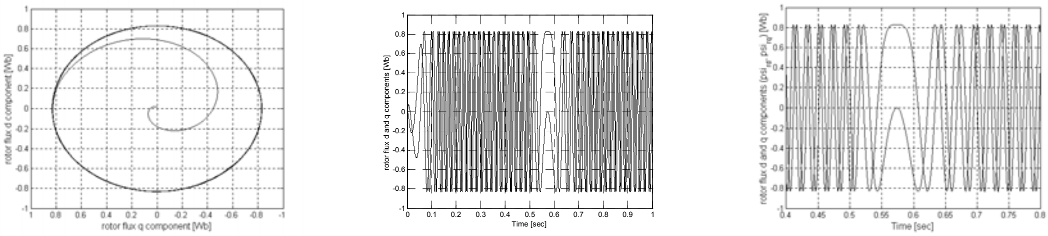

Fig. 9. Rotor-flux space-phasor trajectory, its d-q components versus time - starting and reversing detail diagrams.

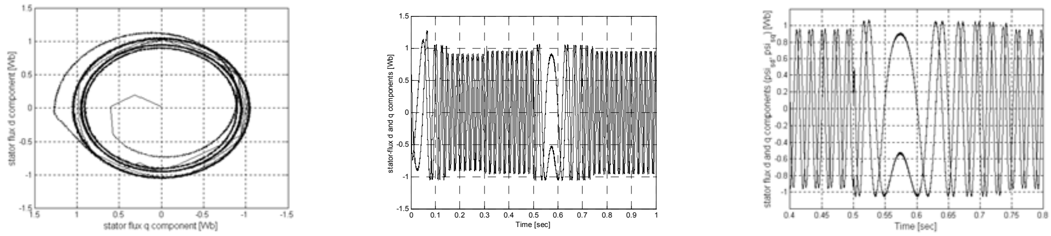

Fig. 10. Stator-flux space-phasor trajectory, its d-q components versus - starting and reversing detail diagrams.

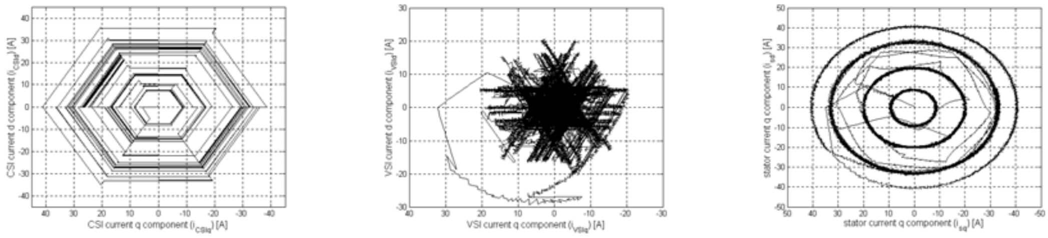

Fig. 11. Space-phasor trajectories of the CSI currents, VSI currents and stator currents.

6. CONCLUSION

The results show that the tandem converter produces an improved output current waveform due to the PWM procedure of the VSI. Considering a PWM-VSI equivalent in power to the whole tandem converter and comparing it with the secondary VSI from the tandem, the ratio of the average absolute values of output currents in these converters would be 3.7 [2], [3]. Experimental results are also presented in [4], [5], [6]. Consequently, the tandem converter is a new alternative topological configuration for the conventional voltage- and current-source DC-link frequency converters, joining advantages of the two basic variants. The hardware-software co-design process should decide about which module has to be implemented in CSL and which one in the FPGA. Implementation of a module library allows the fast development and rapid prototyping.

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