POLYPHASE SYSTEMS FOR HIGH-POWER CONTROLLED AC DRIVES. SPECIFICS OF THEIR PARAMETERS AND CONTROL

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Keywords: adjustable speed drives, control

Abstract

Advantages of 2*3-phase, 3*3-phase and 4*3-phase motors are known for high-power controlled AC drives. But model of such system is more complicate. Solutions are proposed for parameters choice of a frequency converter and for special control. Investigation proved that proposed solutions provide realization of advantages of poly-3-phase system. This is confirmed by simulation results for a 3*3-phase synchronous drive on the base of current source inverter (CSI) with pulse-width modulation (PWM).

1. Tasks of the paper

Advantages of 2*3-phase, 3*3-phase and 4*3-phase motors are known for high-power controlled AC drives. Some advantages are seen for a frequency converter for such motor with its modular composition. But such drive has definite specific in parameters choice and in control.

Tasks of the paper:

- to develop mathematical model for a drive with polyphase (for example, 3*3-phase) motor;
- to develop special control system for such drive;
- to investigate features of such system for an example of synchronous drive on the base of PWM CSI.

2. Model of a polyphase drive

Special conversion is proposed for voltages and currents. Let's consider 3*3-phase motor for example. Considered main circuit is shown on Fig. 1.

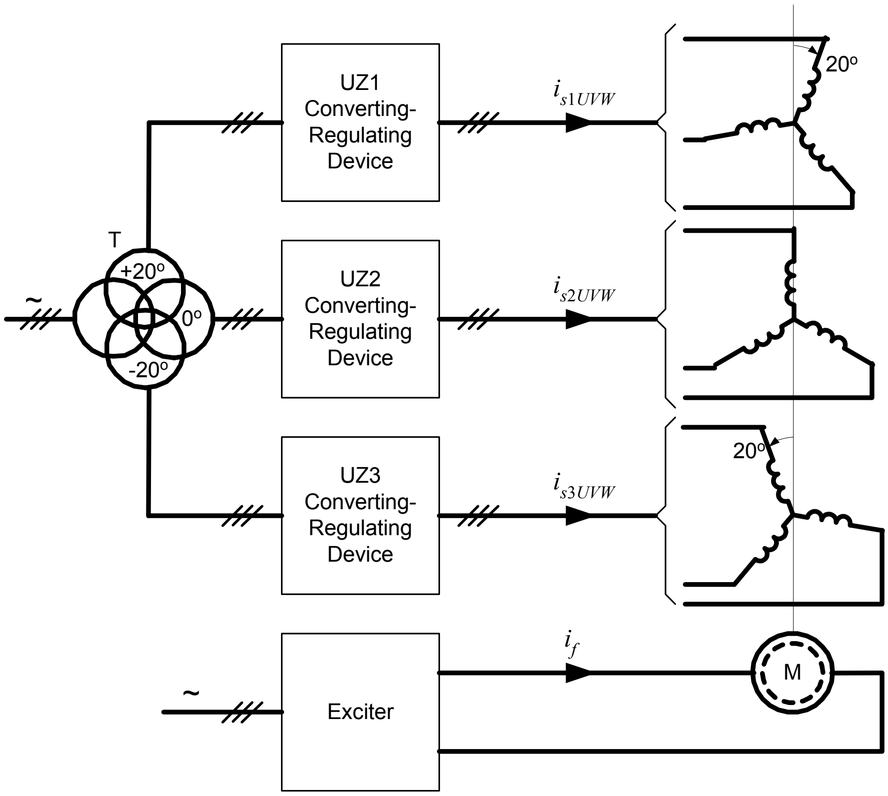

Fig. 1. Drive with 3*3-phase motor

Currents may be represented in such form:

$\mathbf{i}_{s6} = (\mathbf{i}_{s1\alpha\beta1}, \mathbf{i}_{s2\alpha\beta2}, \mathbf{i}_{s3\alpha\beta3})$.

Currents of each 3-phase winding are represented by representing vector in stationary frame of this winding:

It is accepted that winding 1 has space shift $-\pi/9$ (leading winding) and winding 3 has shift $\pi/9$ (lagging winding) relatively winding 2. Then it is possible to transform currents into other 6-dimensinal vector:

$$\mathbf{i}_{sIE} = (\mathbf{i}_{sI}, \mathbf{i}_{sII}, \mathbf{i}_{sIII}) = (\mathbf{i}_{sI}, \mathbf{i}_{sE}); \mathbf{i}_{sIE} = \mathbf{C}_{sE6}\mathbf{i}_{s6}.$$

Matrix of conversion and inverse matrix are:

$$\mathbf{C}_{IE6} = \tfrac{1}{3}\begin{pmatrix} \mathbf{C}(-\pi/9) & \mathbf{1}_2 & \mathbf{C}(\pi/9) \\ \mathbf{C}(-7\pi/9) & \mathbf{1}_2 & \mathbf{C}(7\pi/9) \\ \mathbf{C}(5\pi/9) & \mathbf{1}_2 & \mathbf{C}(-5\pi/9) \end{pmatrix}; \mathbf{C}_{IE6}^{-1} = \begin{pmatrix} \mathbf{C}(\pi/9) & \mathbf{C}(7\pi/9) & \mathbf{C}(-5\pi/9) \\ \mathbf{1}_2 & \mathbf{1}_2 & \mathbf{1}_2 \\ \mathbf{C}(-\pi/9) & \mathbf{C}(-7\pi/9) & \mathbf{C}(5\pi/9) \end{pmatrix}; \mathbf{C}(\gamma) = \begin{pmatrix} \cos\gamma & -\sin\gamma \\ \sin\gamma & \cos\gamma \end{pmatrix}.$$

Model of drive is represented for an example of drive on the base of PWM CSI. Module of the converting-regulating device is shown on Fig. 2.

Structural diagram of the model is shown on Fig. 3. Two parallel channels exist. Main channel with inverter current i_{MI}, and stator voltage u_{sI} influents main field and torque of motor. It includes model of *SM Magnet Circuit* [1] and *Mech-Move* – model of a mechanism with its inertia and its load torque.

Side channel with inverter current i_{ME} and stator voltage u_{sE} is connected with main one through inverter. Machine is present here only with stator leakage inductance.

Input of model is 9-dimensional vector of inverter states z_M. It is defined by outputs of control part. In this case components may be or +1, or 0, or –1. And for this case of synchronous drive an additional input for exciter u_{Gf} exists.

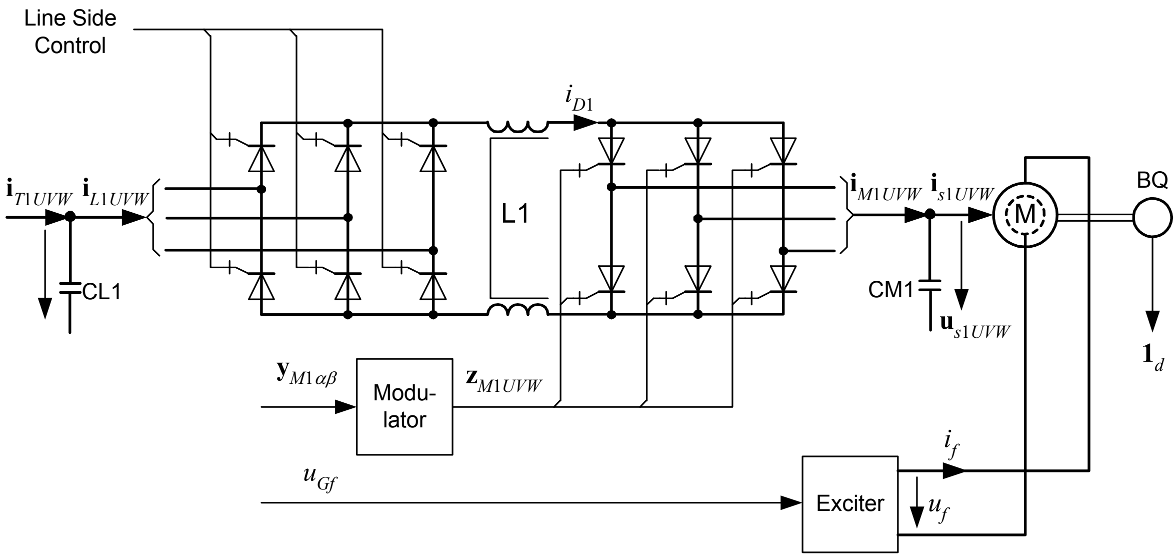

Fig. 2. Synchronous drive on the base of PWM CSI (channel for one 3-phase winding is shown for stator)

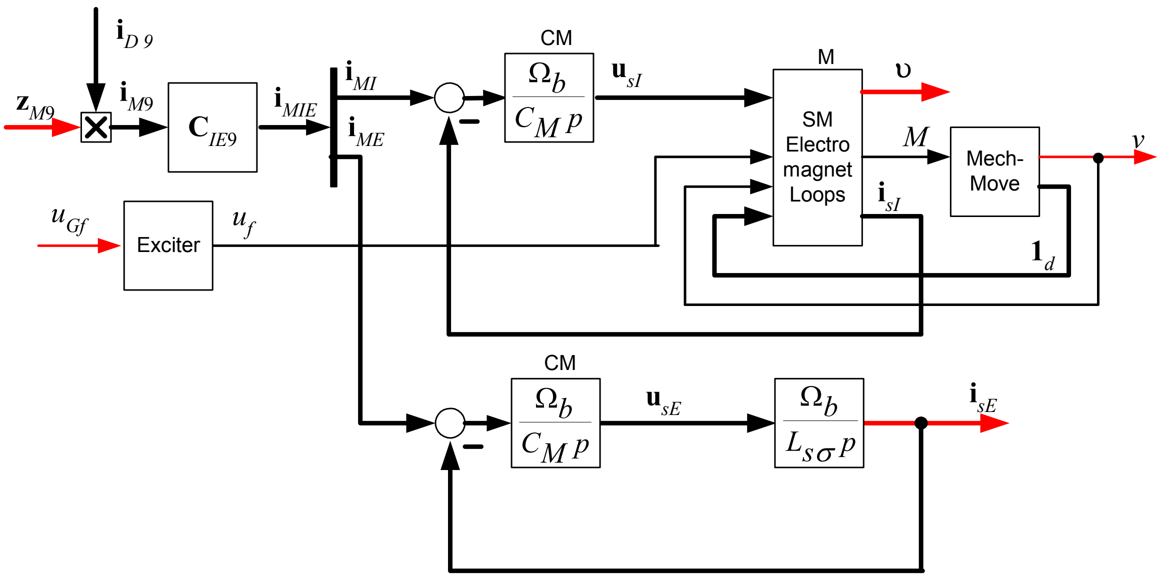

Fig. 3. Structural diagram for control object of the synchronous drive with PWM CSI

As outputs of model velocity v is considered. Vector υ as an additional output representing energy variables of motor, [2]. There is definite freedom in choice of this vector. For example it may be chosen in form $\upsilon = (\psi_\delta, \psi_s)$, where ψ_δ is module for the vector of main flux and ψ_s is module for the vector of full stator flux linkage.

3. Specifics for parameters and control

Side channel with only stator leakage provides more pulsation for currents and higher resonant frequency than main one. And we need more relative capacitance for filter capacitor and sometimes more modulation frequency.

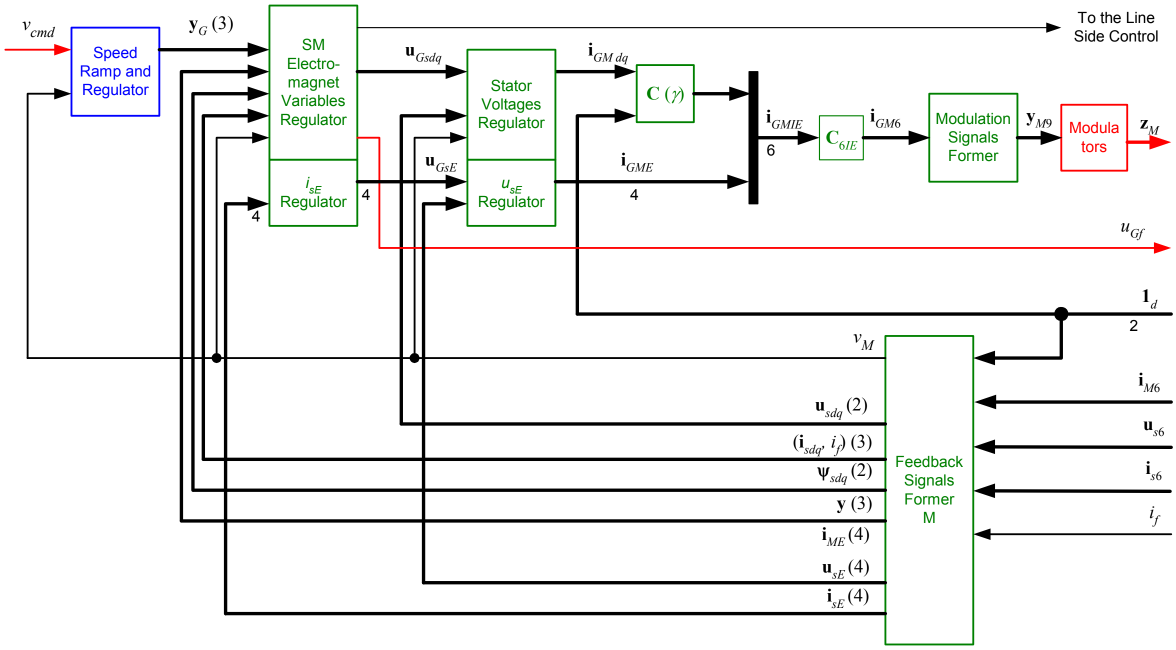

Fig. 4. Functional diagram of control algorithm for the synchronous drive with PWM CSI

Control system should include side channel. Fig. 4 represent control system synthesized on the base of theory of non-linear multi-connected subordinate control [3]. 4-dimensional side channel repeats topology of the main channel. Input of control part is speed command v_{cmd}. *Speed Ramp and Regulator* provides reference y_G for internal loops. Correspondingly *Feedback Signals Former* provides feedback y = (M, υ). Two internal loops exist: for SM electromagnet variables and for stator voltages. Internal loops should implement desired transient operator for reference:

$$\mathbf{y} = \frac{1}{1+(p/\Omega_e)\left[1+\frac{1}{2}(p/\Omega_e)\right]}\mathbf{y}_G .$$

Here Ω_e is bandwidth for the motor electromagnet variables loop.

Side channel operates with zero reference. But discrete features of *Modulator* introduce disturbances in this channel as in main channel. Appropriate parameters of power part and structure of regulators limit influence of these disturbances.

Line side control isn't considered here. It provides necessary DC link current i_D for all the regimes.

4. Simulation results

Simulation is performed for the considered example of drive with parameters of the motor 7 MW, 300/600 rpm, 30/60 Hz. Filter capacitance is C_{CM} = 0.36 p.u. Resonance frequency for stator circuit is 130 Hz. Modulation frequency of the frequency converter is 450 Hz. And relation of modulation frequency to resonant frequency isn't high one. Control part is implemented as discrete one. Sample times for parts of algorithm are: for *Modulator* – T_{s0} = 10 µs, for most of the rest parts – T_{s1} = 100 µs, for *Speed Ramp and Regulator* – T_{s2} = 0.5 ms. Sample times are marked by colors on diagram Fig. 4. Drive is considered with two-zone speed control, with field weakening over base speed.

Bandwidth of the speed control loop is 50 rad/s; this is high quick-responsibility for high-power drive.

Results are represented on Fig. 5. Type check processes of a controlled drive are represented: start without load torque, load step-up, load step-down, deceleration to full stop. Variant with P speed regulator is shown.

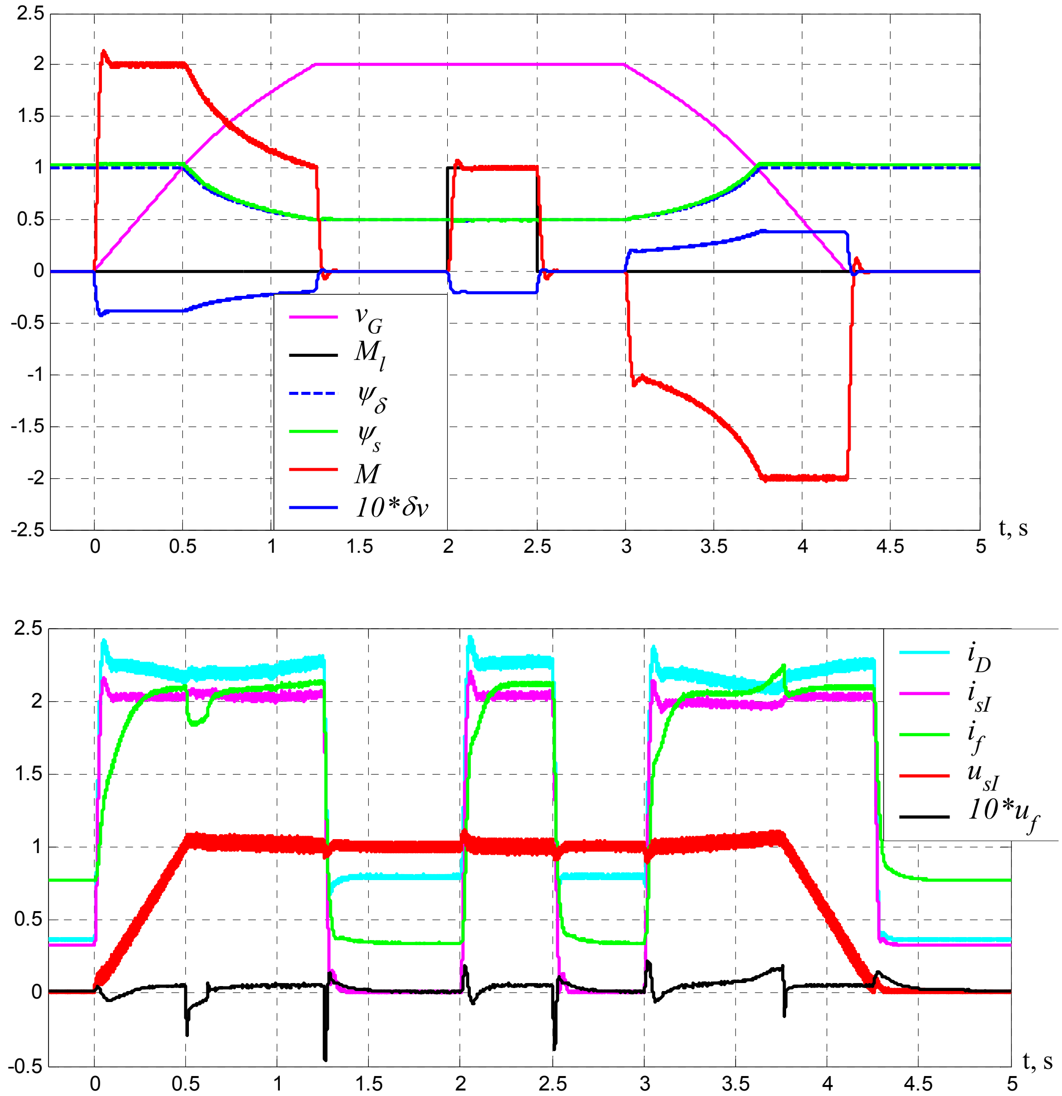

Fig. 5. Processes of the model of a 3*3-phase synchronous drive

Designations for variables are: v_G – velocity reference, M_l – load torque, ψ_s – stator flux linkage (module of representing vector), ψ_δ – main flux (module of representing vector), M – electromagnet torque, $(v - v_G)$ – deviation of velocity from reference, u_f, i_f – excitation voltage and current, u_s = sqrt(u_{sIE} u_{sIE}), i_s = sqrt(i_{sIE} i_{sIE}) – these are modules of 6-dimensional vectors of stator voltage and current. All the variables are represented as relative values with usual base values for the machine.

Steady-state speed is chosen v_{st} =2 to demonstrate drive operation in the upper speed zone also. Dynamical torque for acceleration-deceleration is accepted M_{dst} = 2 and load step is M_{lst} = 1. This load step is implemented in the upper zone with two-times weakened field.

Processes of speed and torque are close to known type processes of a controlled drive with subordinate control, difference is in limit of 5 %. The same is valid for fluxes. Magnitude of torque pulsation is $M_{pm} \approx 0.018$, magnitude of current pulsation $I_{spm} \approx 0.03$ and this for voltage $U_{spm} \approx 0.01$.

Magnitude of torque pulsation is approximately 5-times less than this for a drive with one 3-phase motor winding in the same conditions. Small pulsation in processes of voltage u_s and current i_s demonstrate small pulsation of all the voltages and currents. It is possible to conclude that advantages of poly-3-phase drives are implemented.

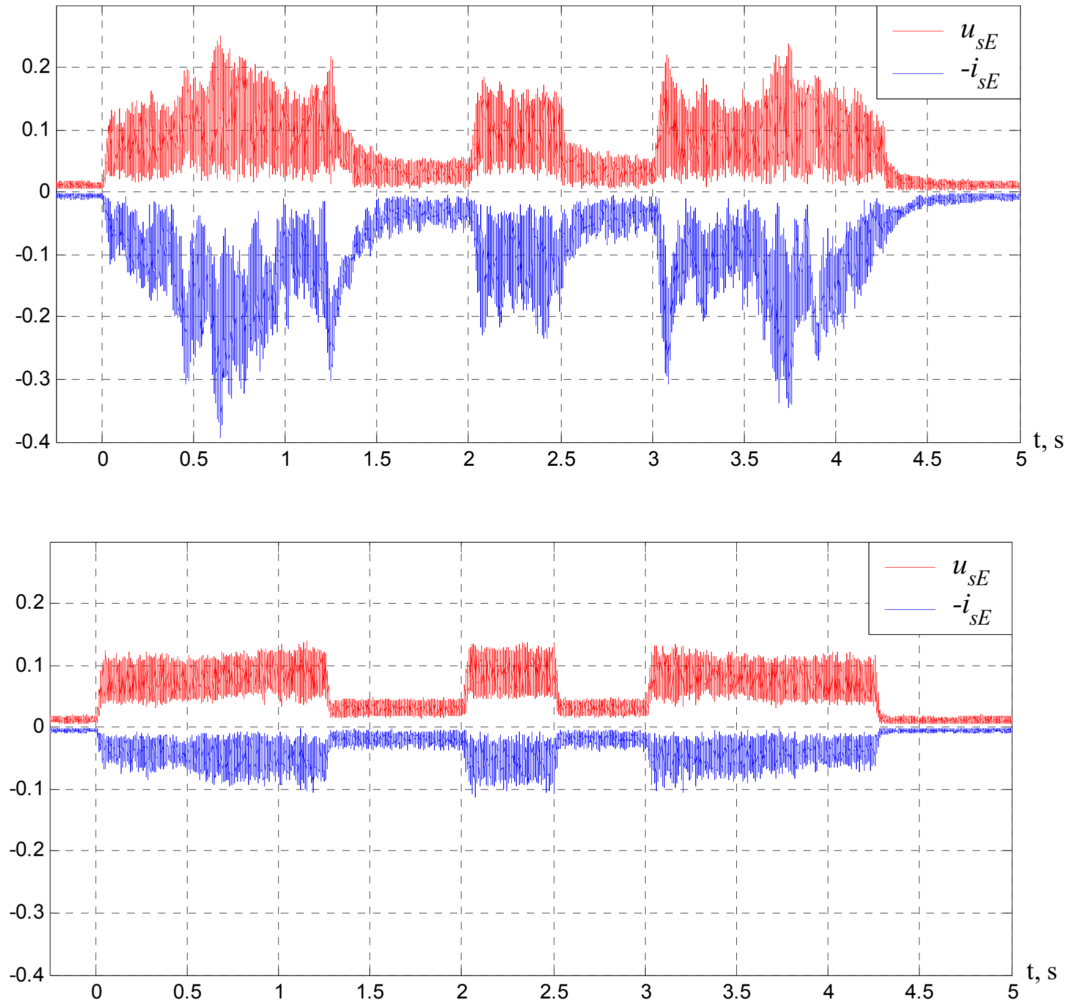

Fig. 6. "Loop" voltages and currents without and with their control

Fig. 6 represents "loop" voltages and currents without their control and with proposed control. Designations are: u_{sE}, i_{sE} modules of 4-dimensional vectors u_{sE}, i_{sE}. We see that control depresses side voltages approximately 2-times and side currents – 4-times.

Forms for one of the stator line-to-line voltage u_{s2AB} and phase current i_{s2A} are shown on Fig. 7. They are represented for a case without control of "loop" currents and with proposed control. We see that depression of side voltages and currents evidently improves form of stator currents.

5. Conclusion

1. Appropriate choice of parameters and control allows to realize advantages of controlled AC drive with poly-3-phase motor.
2. Specifics of parameters choice relate to output filter of the machine converter. It is necessary to take into account resonance with more frequency for "loop" voltages and currents.

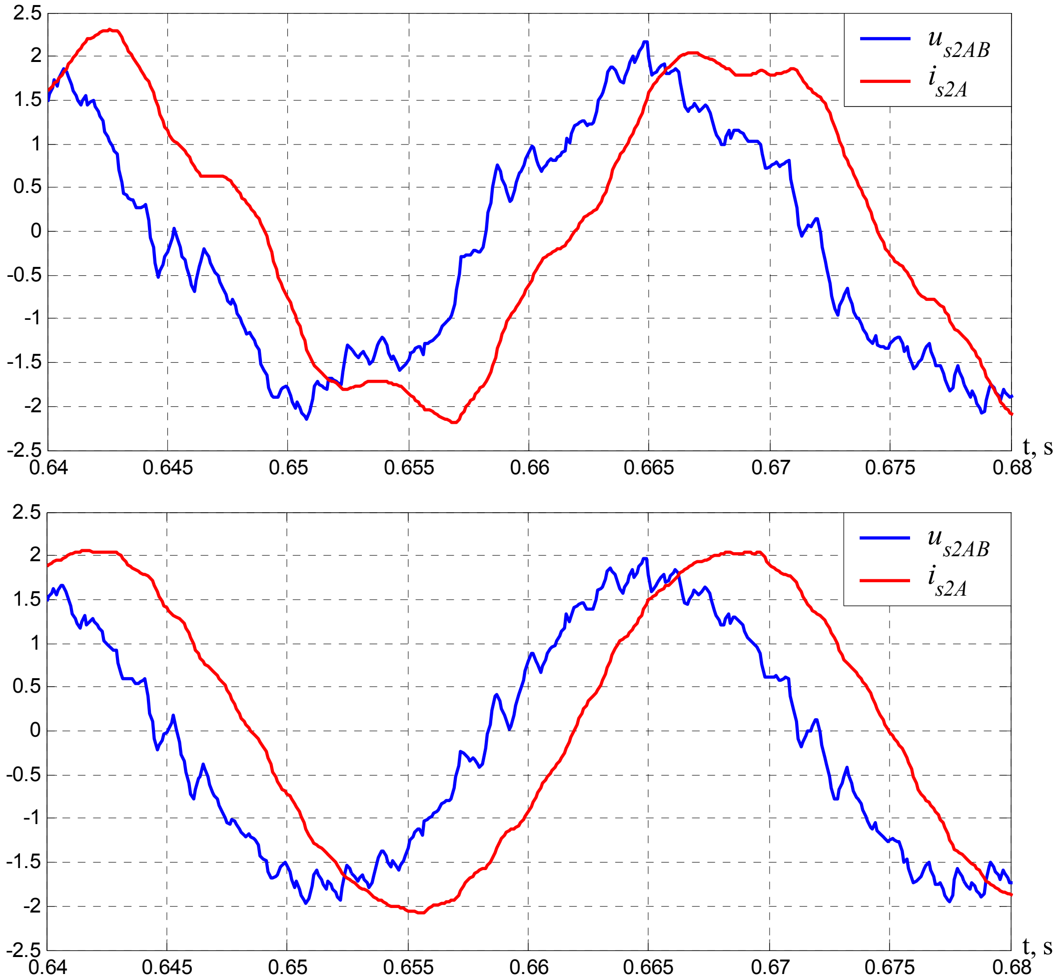

Fig. 7

3. Specifics of control are regulators for "loop" voltages and currents. These provide depression of such voltages and currents and improvement of currents form.
4. Considered example with drive on the base of PWM CSI confirms that such kind of drive is suitable, on level with VSI drives, in all the range of high-power drives including most dynamical ones.

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