ADVANCED MODELS FOR SIMULATION AND CONTROL OF MACHINE-CONVERTER COMPLEXES AND CONTROLLED ELECTRIC DRIVES

Dmitry V. Beliaev, Alexander M. Weinger, Prof., D. Sc., Rockwell Automation/ Allen Bradley, Moscow

Key words: modelling, electric drives, electric machines, control

Special models are considered: synchronous and asynchronous machine with saturation of main magnet circuit, bridge of voltage and current inverter with fully controlled semiconductors, thyristor bridge of a controlled rectifier-inverter. These models are used for simulation and control of machine-converter complexes and controlled electric drives.

1. SUBJECTS OF THE REPORT

Special models are necessary for simulation and control of electric drives and machine-converter complexes. Application fields are as follows:

- computer simulation of a controlled drive as a complete in non-real time;
- computer simulation of power part of controlled drive in real time jointly with real automatic control device;
- using models of machine and converter for synthesis of control algorithm;
- using models as elements of algorithm in real automatic control devices.

Necessary models should take into account only main features of objects that play role in controlled drive as a complex and in drive control.

Such models have been developed for asynchronous and synchronous machine, for bridge of current or voltage inverter with fully controlled semiconductors, for controlled thyristor rectifier-inverter. And they were used in all fields, mentioned above.

Developed models and some experience of their application are subjects of this report.

2. SPECIAL MODELS

2.1. Common terms and designations

Vector is considered here as numbered aggregate of scalars (but not as column matrix) corresponding to definition of higher and linear algebra. Definitions of those are used also for operations with vectors, with vectors and matrices, with matrices. Vectors are designated here with bold characters in the lower case, matrices do with bold characters in the upper case.

2.2. Synchronous machine

Equations. Mainly commonly accepted equations are used. All the variables and parameters are considered as relative values besides of time and time constants. Variables are represented in coordinate system d, q connected with rotor axes.

Equation of voltages is:

$$(p/\Omega_b)\ \boldsymbol{\psi} = \mathbf{u} - \mathbf{R}\ \mathbf{i} - v\ \mathbf{C}_v\ \boldsymbol{\psi}, \qquad (1)$$

Designations are as follows: p – operator of time derivation, Ω_b – base angle frequency, v – velocity, $\boldsymbol{\psi} = (\psi_{sd}, \psi_{sq}, \psi_f, \psi_{cd}, \psi_{cq})$ – vector of flux linkages, $\mathbf{i} = (i_{sd}, i_{sq}, i_f, i_{cd}, i_{cq})$ – vector of currents, $\mathbf{u} = (u_{sd}, u_{sq}, u_f, 0, 0)$ – vector of voltages, $\mathbf{R} = \text{diag}\ (R_s, R_s, R_f, R_{cd}, R_{cq})$ – matrix of resistances,

$$\mathbf{C} = \begin{pmatrix} \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix} & \mathbf{0}(2,3) \\ \mathbf{0}(3,5) & \end{pmatrix}$$ - matrix of EMF connections;

indices are: s – stator, f – excitation winding, c – equivalent damping loops of rotor, d – longitudinal axis, q – transversal axis.

Part of equations of magnet circuit is:

$$\boldsymbol{\psi} = \mathbf{C}_\psi\ \boldsymbol{\psi}_\delta + \mathbf{L}_\sigma\ \mathbf{i}. \qquad (2)$$

Here $\mathbf{L}_\sigma = \text{diag}\ (L_{s\sigma}, L_{s\sigma}, L_{f\sigma}, L_{cd\sigma}, L_{cq\sigma})$ – matrix of leakage inductances,

$$\mathbf{C}_\psi = \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \end{pmatrix}$$ - matrix of axes connections, and

$\boldsymbol{\psi}_\delta = (\psi_{\delta d}\ , \psi_{\delta q})$ – 2-dimensional vector of main flux (flux in air gap).

The rest of equations for magnet circuit expresses the dependence of main flux vector from vector of sum currents $\mathbf{i}_\Sigma = \mathbf{C}_\psi^T \mathbf{i}.$:

$$\boldsymbol{\psi}_\delta = f_\delta\ (\mathbf{i}_\Sigma), \qquad (3)$$

A vector function in (3) without saturation is simple one:

$$\boldsymbol{\psi}_\delta = \mathbf{L}_{m0}\ \mathbf{i}_\Sigma, \qquad (4)$$

where $\mathbf{L}_{m0} = \text{diag}\ (L_{md0}\ , L_{mq0})$ is the matrix of main non-saturated inductances.

Equations (1, 2, 4) provide known simple expression of currents vector **i** through flux linkages vector **ψ**.

Saturation changes features of vector function in (3) not only quantitatively but also qualitatively: axes turn out mutually connected. And expression for vector **i** isn't so simple one.

WV conversion. We introduce a new 2-dimensional vector

$$\boldsymbol{\psi}_w = \mathbf{W}\,\boldsymbol{\psi}, \qquad (5)$$

$$\mathbf{W} = \mathbf{L}_e \mathbf{C}_\psi^T \mathbf{Y}_\sigma, \mathbf{Y}_\sigma = \mathbf{L}_\sigma^{-1}, \mathbf{L}_e = (\mathbf{C}_\psi^T \mathbf{Y}_\sigma \mathbf{C}_\psi)^{-1}.$$

It is possible to show that main flux vector is expressed through new vector and sum currents vector:

$$\boldsymbol{\psi}_w = \boldsymbol{\psi}_\delta + \mathbf{L}_e\,\mathbf{i}_\Sigma. \qquad (6)$$

Analysis shows that matrix $\mathbf{L}_e$ is a diagonal one $\mathbf{L}_e$ = diag (L_{ed} , L_{eq}) with small elements. Thus main flux vector is close to vector $\boldsymbol{\psi}_w$ that is expressed through state vector **ψ**. Equations (3, 6) give non-salient function

$$\mathbf{i}_\Sigma = \varphi_w(\boldsymbol{\psi}_w). \qquad (7)$$

Magnet Circuit. Equations (3, 5-7) provide structural diagram for magnet circuit demonstrated in Fig. 1. Additional matrices in this structure are the following:

$$\mathbf{Y}_{i\psi} = \mathbf{Y}_\sigma(\mathbf{1}(5,5) - \mathbf{C}_\psi \mathbf{W}), \mathbf{K}_{ii} = \mathbf{Y}_\sigma \mathbf{C}_\psi \mathbf{L}_e.$$

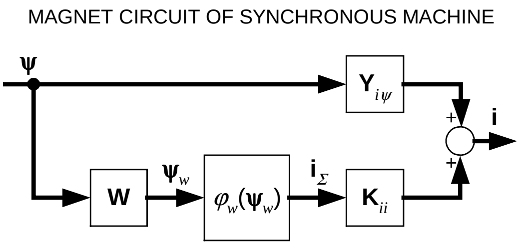


Fig.1

Structural diagram for function (7) that follows equations (3, 6) is shown in Fig. 2.

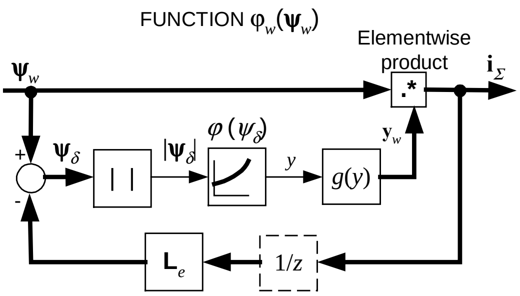


Fig.2

Characteristic of main magnet circuit is used here in such form:

$$\mathbf{i}_\Sigma = \mathbf{A}_{dq}\,\varphi(|\boldsymbol{\psi}_\delta|)\,\boldsymbol{\psi}_\delta, \qquad (8)$$

where matrix $\mathbf{A}_{dq}$ = diag (1, K_{dq}), $K_{dq} = L_{md0}/L_{mq0}$, function φ is a part of machine non-load characteristic

$$i_{\Sigma d} = \varphi(\psi_{\delta d})\,\psi_{\delta d}. \qquad (9)$$

Vector function $g(y)$ in structure Fig.2 is defined by equations:

$$y_{wd} = 1/(L_{ed} + 1/y),\; y_{wq} = 1/(L_{eq} + 1/(K_{dq}\,y)). \qquad (10)$$

"Elementwise product" in structure Fig.2 means operation:

$$\mathbf{i}_\Sigma = (y_{wd}\,\psi_{wd}\,,\, y_{wq}\,\psi_{wq}) = \text{diag}\,(y_{wd}\,,\, y_{wq})\,\boldsymbol{\psi}_w\,. \qquad (11)$$

Such operation isn't defined in vector algebra, but it is useful one and provided by Simulink for example.

Algebraic loop in function φ_w ($\boldsymbol{\psi}_w$). Such loop exists in structure. And time delay element is shown in feedback as it is used for simulation. But this causes a problem of computation stability. It is proven that enough resource of stability exists with typical parameters of synchronous machine. Small values of elements of matrix $\mathbf{L}_e$ contribute to stability.

Full structural diagram. This is shown in Fig. 3. Inputs of the structure are: vector of voltages $\mathbf{u}_{s\alpha\beta}$ in stator coordinates and excitation voltage u_f. As outputs only velocity v and angle position γ are shown here. Other outputs are possible and they might be formed evidently. Model of mechanical move is a part of structure. Such models are developed for different cases, but they aren't considered here. Element of vector rotation is shown at stator input. It converts stator voltages to d,q system. Link with operator Y shows machine magnet circuit. Electromagnet torque is defined as scalar value:

$$M = \mathbf{i}_s\,\mathbf{J}\,\boldsymbol{\psi}_s, \qquad (12)$$

where $\mathbf{J} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$ is the matrix of vector rotation for 90 degrees.

In case of non-salient pole machine the structure for magnet circuit is evidently simplified.

Asynchronous machine. It is possible to use for asynchronous machine the same coordinate system d, q as for synchronous one with evident changes in vectors and matrices of model. And experience shows that that such model operates more reliable than model in coordinates connected with vector of rotor flux. A cause is that model in d, q axes doesn't use slip. It provides more accuracy with low rotor flux.

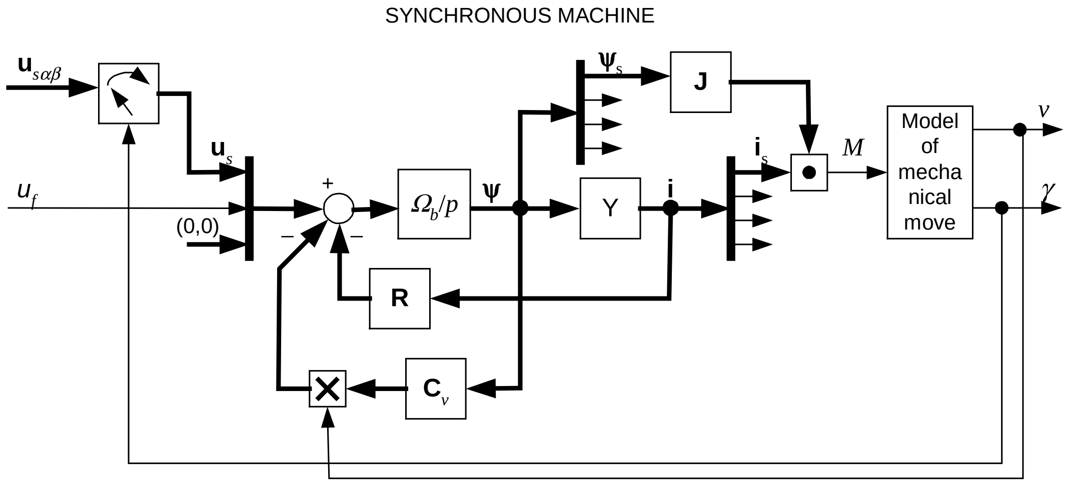


Fig. 3

2.3. Bridge of voltage inverter

Proposed model is simplified essentialy in comparison with known ones.

Allowances are accepted as follows:

- processes of snubber circuits aren't taken in account;
- it is supposed that one and only one valve in each phase is in conducting state for every time moment.

These allowances are suitable for analysis of a controlled drive as a complete. And they simplify structure of voltage inverter and shorten computation time many times.

This bridge and its structural diagram are shown in Fig. 5.

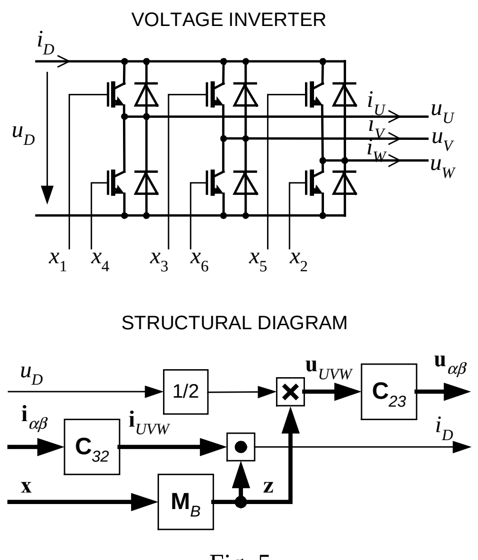


Fig. 5

Such bridge operates with capacitor connected to its DC terminals. Capacitor voltage and AC currents are state variables in a model of controlled drive.

Inputs of structural diagram are DC link voltage u_D, 2-dimensional vector of AC currents $\mathbf{i}_{\alpha\beta}$, 6-dimensional vector of control signals $\mathbf{x}$. Control signals $x1 - x6$ may be 0 or 1. Value 1 corresponds to conducting state of valve Output of structure are 3-dimensional vector of AC voltages $\mathbf{u}_{UVW}$ and DC link current i_D.

Matrix in structure is

$$\mathbf{M}_B = \begin{pmatrix} 1 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & -1 \\ 0 & -1 & 0 & 0 & 1 & 0 \end{pmatrix},$$

and equations are:

$$\mathbf{z} = \mathbf{M}_B\, \mathbf{x},\ \mathbf{u}_{UVW} = (1/2)\, u_D\, \mathbf{z},$$
$$i_D = \mathbf{i}_{UVW}\, \mathbf{z},\ \mathbf{u}_{\alpha\beta} = \mathbf{C}_{23}\, \mathbf{u}_{UVW}. \qquad (13)$$

2.4. Bridge of current inverter with PWM

As in previous case model is simplified essentialy as compared with known models due to disregard of snubber circuits.

It is supposed that for every time moment one and only one valve for each DC terminal is in conducting state.

This bridge and its structural diagram are shown in Fig. 6.

Such bridge operates with 3-phase capacitor battery connected to AC terminals. Voltages of capacitor battery and DC link current are state variables of a model of controlled drive.

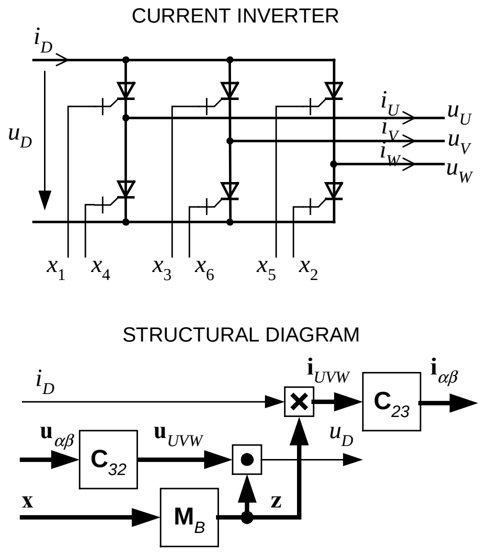


Fig. 6

Inputs of structural diagram are DC link current i_D, 2-dimensional vector of AC voltages $\mathbf{u}_{\alpha\beta}$, 6-dimensional vector of control signals $\mathbf{x}$. Control signals $x1$ – $x6$ may be 0 or 1.Value 1 corresponds to conducting state of valve. Outputs of structure are 2-dimensional vector of AC currents $\mathbf{i}_{\alpha\beta}$ and DC link voltage u_D. Equations are:

$$\mathbf{z} = \mathbf{M}_B\, \mathbf{x},\ \mathbf{i}_{UVW} = i_D\, \mathbf{z},$$
$$u_D = \mathbf{u}_{UVW}\, \mathbf{z}.\ \ \mathbf{u}_{\alpha\beta} = \mathbf{C}_{23}\, \mathbf{u}_{UVW} \qquad (14)$$

2.5. Thyristor controlled rectifier-inverter

Diagram of rectifier-inverter (RI) is shown in Fig. 7.

Known models take into account or snubber circuits or resistance of non-conducting valves. Such model includes as a minimum five independent current loops. Characteristical numbers of matrix for such models includes very large ones that require very small sampling time for simulation.

Proposed model is simplified in comparison with known ones. A limitation is that no more than three thyristors are conducting simultaneously. And only two current loops are considered.

EMFs of power supply, voltage on output terminals of DC link u_{DM} and vector of gating signals $\mathbf{x}$ are considered here as external inputs. Vector $\mathbf{i}_l = (i_{l1}, i_{l2})$ is considered as state vector of RI. The first component is $i_{l1} = i_D$, the second component is connected with commutation current. Vector of line currents is expressed through state vector and control vector:

$$\mathbf{i}_{UVW} = i_{TL1}\, \mathbf{z}_0 + i_{TL2}\, \mathbf{z}_1, \qquad (15)$$

where $\mathbf{z}_0 = \mathbf{M}_B\ \mathbf{x}_0$, $\mathbf{z}_1 = \mathbf{M}_B\ \mathbf{x}_1$, $\mathbf{i}_{TL} = \mathbf{C}_{TL}\ \mathbf{i}_l$, $\mathbf{i}_{TL} = (\ i_{TL1}, i_{TL2})$, $\mathbf{C}_{TL} = (1/2) * \begin{pmatrix} 1 & -1 \\ 1 & 1 \end{pmatrix}$, $\mathbf{x}_1$ is existing control vector; vector $\mathbf{x}_0$ coincides with vector $\mathbf{x}_1$ after end of commutation; it coincides with previous value of control vector while commutation.

Currents i_{l1}, i_{l2} are outputs of integrators that are provided with limitation.

$i_{l1n} = i_{l1(n\text{-}1)} + d\ i_{l1n}$ if $i_{l1(n\text{-}1)} + d\ i_{l1n} \geq 0$
and $i_{l1n} = 0$ if $i_{l1(n\text{-}1)} + d\ i_{l1n} < 0$;
$i_{l2n} = i_{l2(n\text{-}1)} + d\ i_{l2n}$
if $(-\ i_D \leq (i_{l2(n\text{-}1)} + d\ i_{l2n}) \leq i_D$) AND ($\mathbf{x}_1 \neq \mathbf{x}_0$),
$i_{l2n} = i_D$ if $((i_{l2(n\text{-}1)} + d\ i_{l2n}) > i_D)$ AND ($\mathbf{x}_1 \neq \mathbf{x}_0$),
$i_{l2n} = -\ i_D$ if $((i_{l2(n\text{-}1)} + d\ i_{l2n}) < -\ i_D)$ OR ($\mathbf{x}_1 = \mathbf{x}_0$).

Logical signal s_U of end of commutation is formed with condition $(i_{l2(n\text{-}1)} + d\ i_{l2n}) \geq i_D$.

Structural diagram of model is represented on Fig. 8 as Simulink-model.

Additional designations in Fig. 8 are: $\mathbf{B}_{L0} = \mathbf{Y}_{L0}\left(\mathbf{C}_{L10}, -\mathbf{R}_{L10}, \begin{pmatrix} 1 \\ 0 \end{pmatrix}\right)$,

$\mathbf{B}_{L1} = \mathbf{Y}_{L0}\left(\mathbf{C}_{L11}, -\mathbf{R}_{L11}, \begin{pmatrix} 1 \\ 0 \end{pmatrix}\right)$,

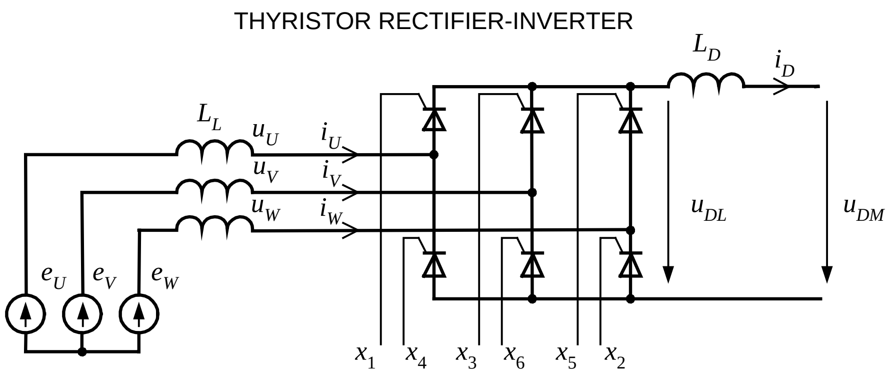
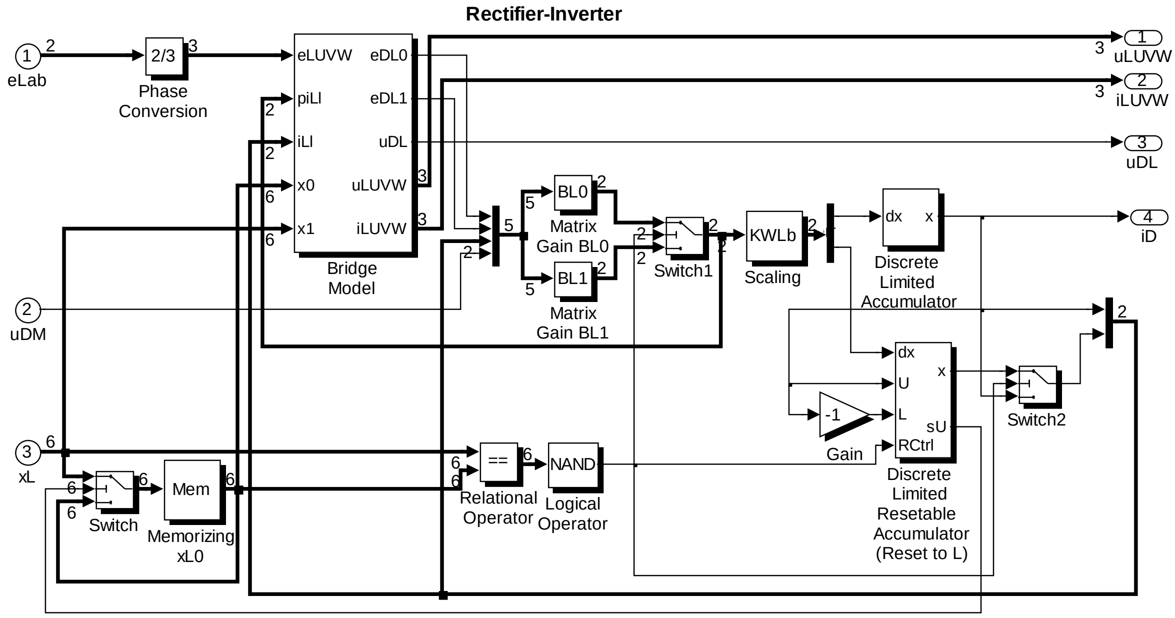


Fig. 7



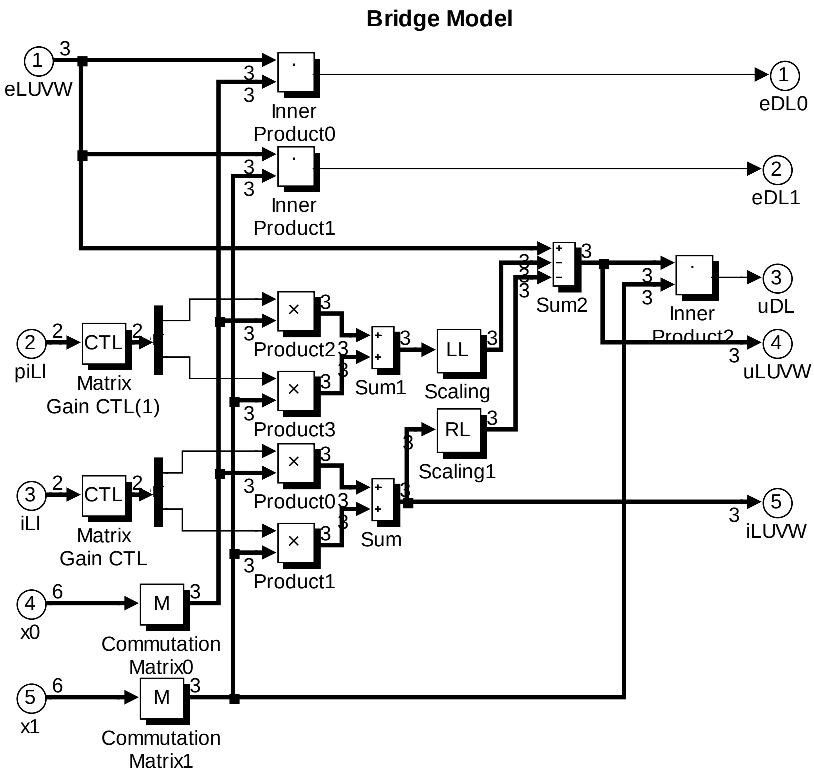


Fig. 8

$\mathbf{Y}_{L0} = \text{inv}\,(\mathbf{L}_{Ll0});$

$\mathbf{Y}_{L1} = \text{inv}\,(\mathbf{L}_{Ll1});$

$\mathbf{L}_{Ll0} = \text{diag}(1.5{*}L_L{+}L_D,\ 0.5{*}L_L);$

$\mathbf{R}_{Ll0} = \text{diag}\,(1.5{*}R_L{+}R_D,\ 0.5{*}R_L);$

$\mathbf{L}_{Ll1} = \text{diag}(2{*}L_L{+}L_D,\ 0.5{*}L_L);$

$\mathbf{R}_{Ll1} = \text{diag}\,(2{*}R_L{+}R_D,\ 0.5{*}R_L);$

$$\mathbf{C}_{L10} = \tfrac{1}{2}\begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix}, \mathbf{C}_{L11} = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}.$$

Models for 12-pulse, 18-pulse RI are developed using this model of 6-pulse RI. Operation of such model is illustrated in part 4.

3. SIMULATION OF CONTROLLED DRIVE AS A COMPLEX

An example of computer simulation is considered. This one is performed for drive including:

- salient-pole synchronous motor;
- frequency converter with 18-pulse thyristor line converter, DC link and current inverter with PWM as machine converter;
- thyristor DC exciter;
- control system synthesized on the base of theory of non-linear multi-linked subordinate control systems [1].

Parameters are accepted those of plate rolling mill main drive 4MW, 40/80 rpm, 6/12 Hz.

Processes are shown in Fig. 9. These are: acceleration – load step-up – load step-down – deceleration. Two-zone speed control is implemented with field weakening in upper zone. Maximal torque and acceleration in upper zone are assigned here as decreasing with speed. Variables are registered as follows: v_{ref} – speed reference, $\psi_{F\delta}$ - filtered main flux, M_F – filtered torque, v – speed, i_{RFD} – filtered DC link current; bandwidth of filters is 1000 rad/s.

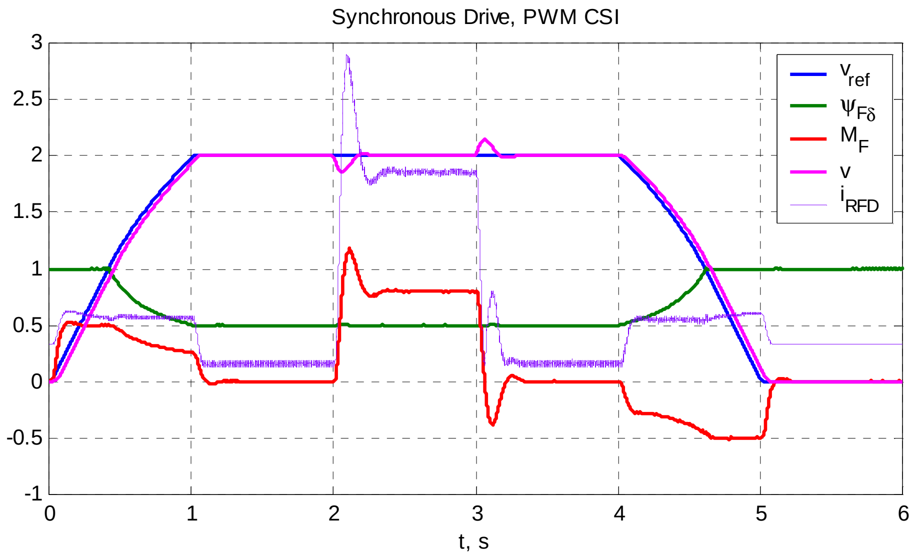


Fig.9

Simulation helped to solve following problems:

- checking control algorithm including sample times for its different parts;
- elaboration of relations for maximal currents and voltages which define parameters of frequency converter and exciter;
- elaboration of requirements to motor especially to parameters of damping cage.

As for processes they have desired predictable form.

4. SIMULATION OF A CONTROLLED DRIVE POWER PART IN REAL TIME

This simulation provides test bench for high-power controlled drives on the base of modern technology. Real control device operates with computer model of power part. Such complex provides possibilities:

- to check most of drive regimes concerning load and power supply including extremal ones; it is impossible or too expensive to create such regimes in usual test bench;
- to predict drive features for concrete application;
- to fix problems with concrete application of drive;
- to train personnel in real situations.

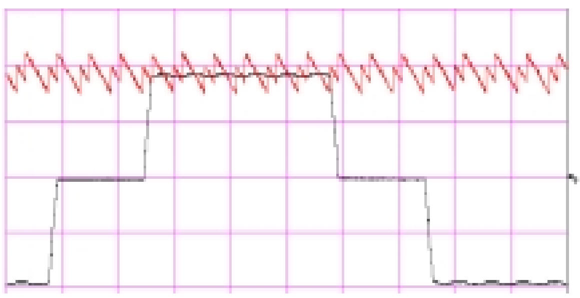


Fig. 10. ______ u_{DL} , ______ i_{L0U} , time division 2 ms

Results are represented for drive mentioned in part 3. Model of object operates with sample time T_{s0} = 40 μs for the shortest computation cycle.

Fig. 10 shows two of feedback analog signals going outside computer model to real control device. Signals are registered by external scope. Commutation and intercommutation intervals are seen.

5. MOTOR MODEL AS AN ELEMENT OF CONTROL ALGORITHM

5.1. Motor model in algorithm of electromagnet variables regulator

Control loop of motor electromagnet variables regulator is one of internal loops of a drive control system that is synthesized according theory of non-linear multi-linked subordinate control systems [1]. Control loop is shown in Fig. 11.

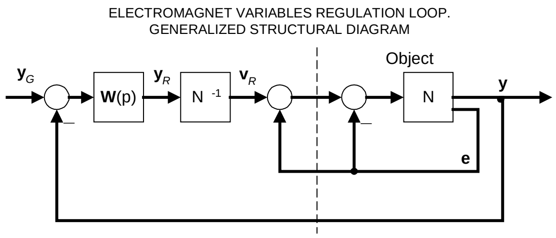


Fig. 11

Here $\mathbf{W}(p)$ is a desired transient matrix of open loop, N is transient operator of object in this loop. Vector $\mathbf{y}$ is vector of regulated electromagnetic variables, here it is represented as $\mathbf{y} = (\psi_\delta, i_{s\rho}, M)$, $i_{s\rho}$ is a component of stator current directed on main flux vector. $\mathbf{y}_G$ is reference for electromagnetic variables. Vector $\mathbf{y}_R = (\psi_{R\delta}, i_{Rs\rho}, M_R)$ coincides with regulated vector $\mathbf{y}$ if operation is ideal one. Operator N^{-1} forms vector

$$\mathbf{v}_R = \mathbf{R}\,\mathbf{i}_R + (p/\Omega_b)\,\boldsymbol{\psi}_R + \nu\,\mathbf{C}_v\,\boldsymbol{\psi}_R \qquad (15)$$

with relations for corresponding vectors of motor.

Structure for operator N^{-1} is shown in Fig. 12. Link with function $f_{\rho\tau}$ designates evident operations to provide vector "stator currents" $\mathbf{i}_{Rs\rho\tau}$ in coordinates ρ, τ where ρ axis is directed on main flux and τ axis is orthogonal leading one.

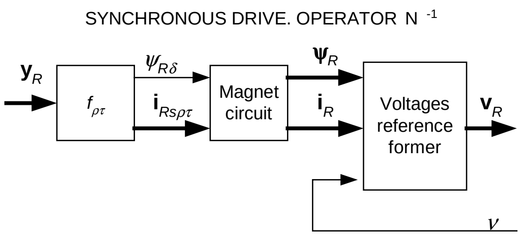


Fig. 12

Magnet circuit model must solve here inverse task as compared with model in 2.1. Difficulty is to find direction of main flux in d, q frame.

An important feature of synchronous motor is found. We consider vector

$$\boldsymbol{\psi}_Q = \boldsymbol{\psi}_\delta + \mathbf{L}_{c\sigma}\,(\mathbf{i}_\Sigma - \mathbf{i}_s), \qquad (16)$$

where $\mathbf{L}_{c\sigma} = \mathrm{diag}(L_{cd\sigma}, L_{cq\sigma})$. It is evident that

$$\psi_{Qq} = \psi_{cq}. \qquad (17)$$

It is possible to accept with small error for regulator:

$$\boldsymbol{\psi}_{RQ} = \boldsymbol{\psi}_{R\delta} + L_{cq\sigma}\,(K_{dq}\,\varphi(\psi_\delta)\,\boldsymbol{\psi}_{R\delta} - \mathbf{i}_{Rs}). \qquad (18)$$

In block *Magnet Circuit* of regulator vector $\boldsymbol{\psi}_{RQ}$ is formed in ρ, τ frame and vector $\boldsymbol{\psi}_{Rc}$ in d, q frame is state vector of regulator. Relation (17) is used to define vector $\boldsymbol{\psi}_{RQ}$ in d, q frame and to form angle ϑ_R between ρ and d axes. Then all the vectors are converted to d, q frame, derivative for $\boldsymbol{\psi}_{Rc}$ vector and outputs of magnet circuit are formed.

5.2. Motor model in algorithm of indirect measurement of velocity and position

A variant of structure for such algorithm is represented in Fig. 13.

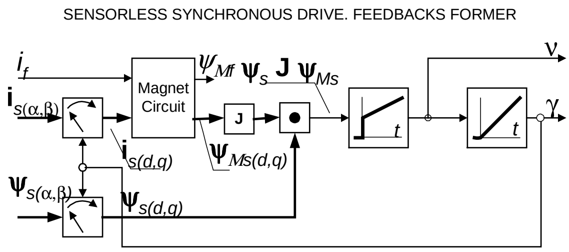


Fig. 13

Inputs of structure are current feedbacks and converted voltage feedback – vector $\boldsymbol{\psi}_{s\alpha\beta}$. A local servo-system is organized with model of magnet circuit. Inputs of model are currents $\mathbf{i}_s$, i_f (in d, q frame). Converter of vector rotation is controlled by output signal of structure – angle γ. The second converter transforms measured flux vector to d, q frame. Two flux vectors are compared on input of PI regulator: output of magnet circuit and measured one. Quick-responsible servo-system provides coincidence of vector directions with small static and dynamic errors.

6. EXPERIENCE OF PRACTICAL APPLICATION OF MODELS

6.1. Models in real control devices

An example is a synchronous drive on the base of LCI. Output ratings of frequency converter are 3.3 kV, 1.4 kA, 50 Hz. Drive is used as frequency starter for synchronous motors of turbo-compressors 20 MW, 3000 rpm. Motor starts through tap 3.3 kV.

Considered regulator and indirect measurer of velocity and position are used in this drive with positive results. Drive operates as synchronous one beginning from zero speed. Initial rotor position is defined while excitation which is provided before beginning the start process. In the lowest speed zone each commutation of inverter is provided with interruption of DC link current. In speed zone over 0.1 n_N commutation is provided by motor counter-EMF. Demagnetizing component of stator current is turned on for this zone by corresponding reference i_{Gsp}. Stator voltage is limited, and in the highest speed zone flux reference is decreasing with speed.

Indirect velocity/position measuring operates reliable. Stable continuous drive operation is provided beginning from 1 % of rated speed. Regulator of motor electromagnet variables provides desired dynamics for this 3-dimensional loop. Drive has been operating since 1997. Detailed description was represented in [2].

6.2. Practical use of simulation results

The last example is a synchronous drive of grinding ball mill 4 MW, 150 rpm, 6 kV, 50 Hz on the base of PWM CSI. Specific of this drive is large stalling torque – up to rated one. And this is a sensorless drive. Other specific feature is a necessary regime of synchronization with power system and switching to power system. Simplified method is used for this regime: switching with some no-current pause without initial over-speed, switching without advanced equalizing of stator voltage to system voltage.

Simulation was performed before drive commissioning. It provided reliance in successful results of project and expedient values for some programmable parameters.

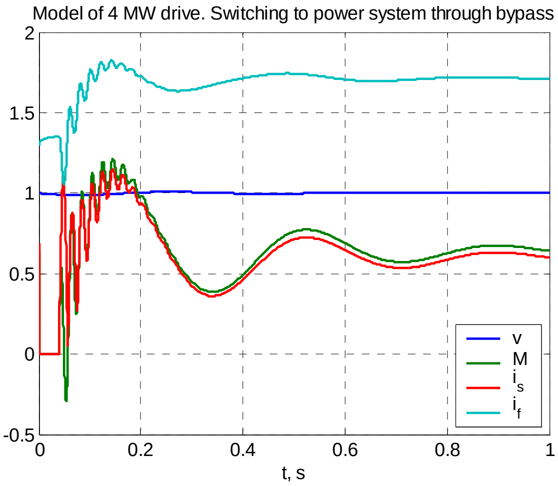


Fig. 14

As an example simulated processes are shown in Fig. 14 for switching to power system.

And an oscillogram registered while drive commissioning is shown in Fig. 15.

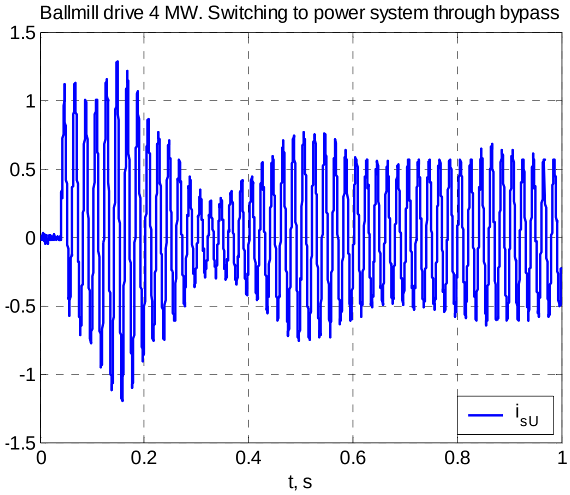


Fig. 15

Process of stator phase current i_{sU} on this oscillogram may be compared with process i_s of module of stator current vector (and envelope for phase currents) in Fig. 14. It is possible to note good correspondence of processes. Other processes that were registered while drive commissioning correspond to simulation results also. Drive operates with settings for parameters that were defined by simulation.

This experience is successful one.

7. CONCLUSION

Developed models are useful for simulation of different kinds of controlled drives, for test installations with computer model of drive power part, for implementation in control algorithm of high-quality drives.

REFERENCE

1. Weinger A. The controlled synchronous drive.- Moscow, Russia: Energoatomizdat, 1985-. 224 ps (Russian).
2. Novakovsky A., Shakaryan Yu., Vinitsky Yu., Weinger A. Improvements in automatic control of synchronous machine with machine commutated current inverter.- International Conference on Electrical Machines, September 2-4, 1998, Istanbul, Turkey.- V. 1/3, pp. 78-82.