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DEFINITION OF CONTROL PARAMETERS OF POWER ENERGY CONVERTER FOR DIRECT CURRENT MACHINES TESTING COMPLEXES

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Obtaining of control parameters of power semiconductor energy converter for implementation of loading modes of tested direct current machines is considered. After consideration of testing complex block scheme the loading modes with influence on armature circuit, excitation winding circuit, and combined influence are analyzed. Definition of regression model for obtaining of control parameters of power semiconductor energy converter at excitation winding circuit using experimental design method is considered. The construction principles of automatic compensation system of current variable component at power energy converter circuit are obtained. The algorithms of control system operating at compensating and loading modes are developed. The modeling block scheme of cross-loading control system of direct current machines is designed. After researching of designed modeling block-scheme the conclusion of facilities of compensating and loading modes formation are obtained.

Key words: testing complex, direct current machine, power energy converter, control parameters, loading mode, compensating mode.

ВИЗНАЧЕННЯ ПАРАМЕТРІВ КЕРУВАННЯ СИЛОВИМИ ПЕРЕТВОРЮВАЧАМИ ЕНЕРГІЇ В КОМПЛЕКСАХ ДЛЯ ВИПРОБУВАННЯ МАШИН ПОСТІЙНОГО СТРУМУ

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Розглянуто питання розрахунку параметрів керування силовими напівпровідниковими перетворювачами енергії для реалізації навантажувальних режимів випробуваних машин постійного струму. Розглянуто блок-схему комплексу для випробування й проаналізовано режими навантаження із впливом на якірне коло, на коло обмотки збудження та комбінованим впливом. Розглянуто питання використання методу планування експерименту з метою побудови регресійної моделі для визначення параметрів керування напівпровідниковими перетворювачами енергії в колі обмотки збудження. Розкрито принципи побудови системи автоматичної компенсації змінної складової струму в колі силового перетворювача. Наведено алгоритми роботи системи керування в режимах компенсації та навантаження. Розглянуто блок-схему моделі системи керування взаємним навантаженням машин постійного струму, за дослідженням якої зроблено висновки щодо можливості формування режимів компенсації та навантаження.

Ключові слова: випробувальний комплекс, машина постійного струму, перетворювач енергії, параметри керування, навантажувальний режим, режим компенсації.

PROBLEM STATEMENT. Estimation of operating capacity of direct current machines (DCM) is important up-today problem through ageing and wearing of operated machines.

This problem at most part of enterprises is solved by creating repair departments. But such departments have own limitations, such as: decreasing reliability of electrical equipment through insufficient level of proficiency of repair staff, unavailability of testing and diagnostic equipment, breach of repair technology. So is very important to carry out after repair testing.

Sufficient information about DCM repairing quality can be received under testing with DCM parameters definition and their correspondence to rated parameters, mechanical properties and tolerance to mechanical and current loads definition. Such after repair testing allows checkout DCM in corpore and machine correspondence to rated requirements.

Symbolically operating modes of electrical machines (EM) separated to setting, running-in and loading modes. In turn loading modes separated to manufacturing and artificial modes leaded for the purpose of rated verifying tests and diagnostics [1, 2–4].

Loading under after repair testing is described by loading mode implementation using load simulator. This load simulator is presented by test bench with varied embodiment consisted of driving and auxiliary systems for conversion between different types of energy and for conversion processes control. According to [1] such test benches are similar to industrial drive systems.

Definition of electrical equipment capabilities after scheduled or overhaul repair is carry-out through several steps:

- definition of EM output parameters for ensure electrical tolerance of insulation;
- definition of EM electromagnetic parameters;
- EM testing on thermal tolerance under load with specified loading mode;
- definition of operating characteristics subject to overload capacity of current and torque, stability and quality of commutation etc.

Implementation of lasts two steps became realizable using test complexes with dynamic or mutual loading of EM [1, 5, 6]. Sense of dynamic loading systems consists in creating of specified control actions of power semiconductor energy converter at power and winding circuits. This specified control actions simulate cycled energy conversion processes between supply, EM and other energy converters.

Design of electrical equipment based on energy conversion processes requires researches in field of such systems principle development, specified control actions forming, researching of energy conversion processes etc.

According to [1, 6] loading modes for DCM can be formed by influence on armature circuit, excitation winding circuit, and by combined influence. Control actions of power semiconductor energy converters consist of zero-frequency component and sum of harmonic components.

The number of harmonic components is determined by number of unknowns of EM electrical equivalent circuit. This number of harmonic components forms diagnostic combined equations [1, 5].

Therefore it is necessary to determine harmonic components of control voltage of semiconductor converters for each tested EM by calculation or experimental way.

The objective is method analysis of control parameters definition for power energy converters at direct current machines testing complexes.

EXPERIMENTAL PART AND RESULTS OBTAINED. Prospective direction of DCM loading systems designing and researching is development of dynamic loading systems (DLS) theory, presented in base at [1] and developed at [6–9].

In papers [1, 10, 11] loading unit consists of power energy converter – EC1, tested DCM – M1, energy converter at excitation winding circuit – EC2. In this case block scheme of testing complex has structure as shown in Fig. 1: transformer – TV; load DCM – M2; excitation windings – FW1, FW2; energy converter at excitation winding circuit of load DCM – EC3, control systems of energy converters – CS; basic frequency generators – FG; storage compensation devices – SCD.

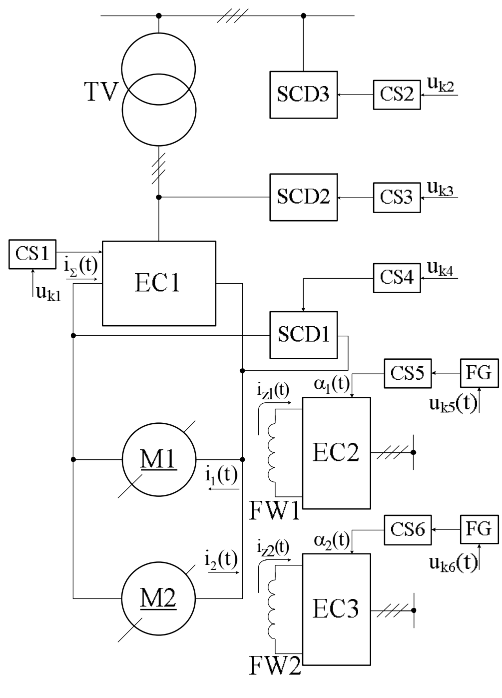

Figure 1 – Block scheme of testing complex

Parameters determining operating mode of DCM are varying. Control actions influence on varying of supply voltage, excitation current, armature resistance and inductance. Results vectors of loading are armature current $i(t)$ and angular velocity $\omega(t)$. For presented loading unit equations of electromagnetic and electromechanical equilibrium are:

$$u(t) = \frac{d}{dt}\left(L_a(t)i(t)\right) + kF(t)\omega(t) + R_a(t)i(t)\,; \quad (1)$$

$$kF(t)i(t) = M_o(t) + \frac{d}{dt}\left(\omega(t)J(t)\right), \quad (2)$$

where $L_a(t)$, $R_a(t)$, $M_o(t)$, $J(t)$, $u(t)$, $i(t)$ – time dependences of armature circuit inductance, armature ohmic resistance, motor operating torque, moment of motor inertia, supply voltage and motor armature current.

After substitution (2) to (1) we get:

$$\begin{aligned} u(t)i(t) &= \frac{dL_a(t)}{dt}i^2(t) + L_a(t)\frac{di(t)}{dt}i(t) + \\ &+ M_o(t)\omega(t) + \frac{d\omega(t)}{dt}J(t)\omega(t) + \\ &+ \frac{dJ(t)}{dt}\omega^2(t) + R_a(t)i^2(t) = \\ &= p_L(t) + p_M(t) + p_k(t) + p_e(t) = p_\Sigma(t), \end{aligned} \quad (3)$$

where $p_\Sigma(t)$, $p_L(t)$, $p_M(t)$, $p_k(t)$, $p_e(t)$ – instantaneous values of energy converter power, inductance power, mechanical output power, power of motor armature kinetic energy varying, power loss of ohmic resistance of armature circuit:

$$p_\Sigma(t) = u(t)i(t)\,;$$

$$p_L(t) = \frac{dL_a(t)}{dt}i^2(t) + L_a(t)\frac{di(t)}{dt}i(t)\,;$$

$$p_M(t) = M_o(t)\omega(t)\,;$$

$$p_k(t) = J(t)\frac{d\omega(t)}{dt}\omega(t) + \frac{dJ(t)}{dt}\omega^2(t)\,;$$

$$p_e(t) = R_a(t)i^2(t)\,.$$

Under implementation of loading mode consumed power of converter or power returned to supply must be equal to rated power of loading object. From equation (3) we can obtain different loading modes realized by control parameters assignment. The loading mode duration greatly exceeding duration of electromagnetic and electromechanical transient processes is mandatory requirement.

The analysis of [1, 6, 9] shows possibility of dynamic loading modes forming by varying of each parameters defining machine properties. Facilities of loading modes can be determined using analysis of electric and mechanical equilibrium equations, power balance equation. Thereby the dynamic loading modes of DCM without mechanical joint of load machines can be formed using control actions of processes of supply energy accumulated at rotating units and electromagnetic energy.

According to [1] implementation of DLS can be carrying out using converters at armature and excitation winding circuits (Fig. 1). In the load scheme with influence on armature circuit tested motor M1 connects to supply voltage through thyristor reversible converter EC1 controlled by control system CS1. Motor excitation realized through converter EC2 controlled by control system CS5.

Mean value of rectified voltage at output of thyristor converter is varying by law

$$u_d(t) = U_{dc} + U_{dm}(t),$$

where U_{dc}, U_{dm} – constant and variable components of rectified voltage.

Variation law of U_{dm} component defines basic loading and energy datum of system. This law correspond sinusoidal, trapezoidal, rectangular voltage etc.

We present variation law of rectified voltage according to [1]

$$u_d(t) = U_{dc} + U_m \sin\Omega t, \qquad (4)$$

where U_m – amplitude of rectified voltage variable component; Ω – frequency of variable component.

In the case of ohmic resistance and inductance of armature circuit, inertia moment and magnetic flux are constant values, dependence of machine armature current is

$$i(t) = I_c + \frac{U_m}{z_a}\sin(\Omega t + \varphi), \qquad (5)$$

where z_a – module of machine armature total resistance,

$$z_a = \sqrt{R_a^2 + \left(\Omega L_a - 1/\Omega C\right)^2};$$

C – motor dynamic capacitance,

$$C = J/(kF)^2;$$

φ – shift angle of armature current relative to rectified voltage [1, 9],

$$\varphi = a\tan\left(\frac{\Omega L_a - 1/\Omega C}{R_a}\right).$$

At presented scheme with some value of parameter C armature circuit total resistance equal to ohmic resistance. Therefore under minimum amplitude of rectified voltage variable component the maximum of load current can be obtained. Voltage loss of armature circuit is 5–7 % of rating value and parameter U_m averages at 5–7 % of rating value [1].

Armature circuit current is alternating-sign signal. Therefore next features of power consumption mode can be separated: integral value of active power consumed from supply at period of rectified voltage variable component is equal to general power loss of ohmic resistance and power loss of idling torque; reactive power consumed from supply by converter is oscillating signal with double average frequency. Limitations of presented scheme are reactive power oscillating, approximately equality between rated power of converter EC1 and tested motor power. Under loading system operating armature current switches between gate groups, so estimated current of gating circuit and rated power of EC1 periodically decrease in half [1, 6, 9].

At loading system with influence on control loop of machine flux (Fig. 1) frequency of voltage variable component of converter EC2 average at 0,3–1,0 Hz in comparison to duration of excitation winding transient process. Armature circuit supplied by reversible converter EC1 with constant control angles of gate groups. This ensures constant mean value of angular velocity under testing [6, 9]. Control signal of converter EC2 consists of constant and variable components, so voltage of excitation winding circuit is

$$u_z(t) = U_{zc} + U_{zm}\sin\Omega t, \qquad (6)$$

where U_{zc}, U_{zm} – constant component and amplitude value of variable component of excitation voltage.

Inductance of excitation circuit is constant value because varying of excitation current occurs only on linear range of magnetization curve of machine induction coil. The dependence of excitation current is

$$i_z(t) = I_{zc} + \frac{U_{zc}}{z_z}\sin(\Omega t + \varphi), \qquad (7)$$

where I_{zc} – constant component of excitation circuit current; z_z – module of excitation circuit total resistance,

$$z_z = \sqrt{R_z^2 + (\Omega L_z)^2}.$$

If we take excitation current proportional to magnetic flux, equation of tested machine behavior under influence on excitation circuit are

$$\begin{gathered} i(t)kF(t) = M_{nx} + J\frac{d\omega(t)}{dt}; \\ u_d(t) = i(t)R_a + L_a\frac{di(t)}{dt} + \\ +\omega(t)kF_c + \omega(t)kF_m\sin(\Omega t + \varphi), \end{gathered} \qquad (8)$$

where M_{nx} – idling torque of motor.

Received combined equations are nonlinear. Therefore alternating-sign nonsine current will flows in armature circuit. This current creates alternating-sign active and reactive loads. Energy datum of researched system is equal to representative values of testing scheme with influence on armature circuit. Only in this case control angles of converter EC1 stay constant. Constancy of control angles occurs to phase decreasing of current harmonics generated to supply. Estimated power of converter EC1 has even parameters as at testing scheme with influence on armature circuit, but machine excitation winding supplied by controlled converter EC2 [1, 6, 9].

At the scheme of testing complex (Fig. 1) we can set simultaneous loading mode for two tested machines through bridging of armature currents variable components between electrical machines M1 and M2. Armature circuit voltage specified by control system CS1 of power converter EC1. Excitation windings supplies by converters EC2 and EC3. Through control systems CS5 and CS6 the values of control angles $\alpha_1(t)$ and $\alpha_2(t)$ are set. From power converter EC1 only constant component of current is consumed and it is equal to sum of constant components of machines currents [1, 5, 11]. This allows to decrease power of converter and to use nonreversive converter.

According to [1, 6, 10] excitation currents of electrical machines are

$$i_{z1}(t) = I_{zc1} + I_{zm1}\sin\Omega_1 t;$$
$$i_{z2}(t) = I_{zc2} + I_{zm2}\sin(\Omega_2 t + \pi), \quad (9)$$

where I_{zc1}, I_{zc2} – constant components of excitation winding circuits; I_{zm1}, I_{zm2} – variable components of excitation winding circuits; Ω_1, Ω_2 – frequencies of variable components.

In the case of loading of m equal machines the phase shift angle between variable components of excitation current must be equal to $2\pi/m$ [1, 10].

Given at [5, 6, 9] researches of energy consumption processes under dynamic loading shows what curves of active and reactive power has some features at current limitation mode. One of these features is fast changing under current reverse. It is known what fast changing of reactive power is basic factor of supply voltage rate of change. Other features are double increased oscillation frequency of reactive power compare to action frequency of loading system, and supply voltage oscillations occurred by varying of reactive power are applied to frequency range with hard limitations of voltage quality.

Comparative analysis of loading modes forming methods shows reasonability of motor load using two components of control voltage of converters EC2 and EC3: constant component and alternating-sign component with corresponding harmonic composition formed according to type of influence of excitation windings of electrical machines used at loading modes.

Prospective means of efficiency increasing of testing complex is using of storage compensation devices (SCD1–SCD3 on Fig. 1). SBD supports circulation of alternating-sign current at power circuit. This means reduction at inverter mode of power converter EC1 [5, 10, 12].

For loading and compensatory modes formation at cross-load system without motor shaft mechanical joint under using of transistor converters EC1 and EC2 at excitation winding circuits of machines M1 and M2 it is necessary to specify basic parameters influencing on mentioned modes:

- duty factors of control pulses of converters at excitation winding circuits of tested motor γ_1 and compensator γ_2;
- shift angle of control pulse of converters at excitation winding circuit of compensator φ_2.

Subject to correlation between tested motor power and compensator power values of mentioned basic parameters will be different. For the purpose of researching this problem at [13] the task of mathematical model design is solved. Designed mathematical model supports estimation of control parameters of energy converters at testing complex of DCM without motor shaft mechanical joint. The experimental design method is used to achieve this aim.

Experimental factors are $x_1=\gamma_1$; $x_2=\gamma_2$; $x_3=\varphi_2$.

Response functions of designed mathematical model are effective values of currents of tested motor I_{1ef}, compensator I_{2ef} and power converter $I_{\Sigma ef}$.

Variation intervals of experimental factors are

- for x_1 and x_2 – $0{,}45..0{,}95$;
- for x_3 – $0..\pi$.

Equation of response functions in general is

$$y = a_0 + \sum_{i=1}^{k} a_i x_i + \sum_{i=1}^{k}\sum_{j=1}^{k} a_{ij} x_i x_j + \sum_{i=1}^{k}\sum_{j=1}^{k}\sum_{q=1}^{k} a_{ijq} x_i x_j x_q , \quad (10)$$

where $a_0, a_i, a_{ij}, a_{ijq}, a_{ii}$ – estimated values of regression coefficients of each response functions.

The control parameters of power converters at cross-load system in case of using electrical machines П31–М with rated power 1.4 kW as tested motor and compensator are obtained (Table 1).

Table 1 – Comparison of control parameters estimation results

Estimation method	Control parameters		
	γ_1	γ_2	φ_2, rad.
Simulating	0,49	0,49	1,57
Combined equations calculating	0,492	0,492	0,887

Comparison of simulation and calculation results (Table 1) shows we can decrease error of parameter φ_2 using automatic system of definition of control parameters of power converters at excitation winding circuits of electrical machines.

At offered cross-load system (Fig. 1) two direct current machines with independent excitation are control objects (one machine operates at loading mode, other – at compensating mode). It is necessary to design control system subject to present nonlinearity of machines processes.

Control of converters at excitation winding circuits of electrical machines must support opposite direction of variable components of armature circuits currents [10, 14]:

$$i_1(t) = I_{c1} + \sum_{m=1}^{\infty} I_{m1}\cos(m\Omega t + \varphi_1);$$
$$i_2(t) = I_{c2} + \sum_{m=1}^{\infty} I_{m2}\cos(m\Omega t + \varphi_2), \quad (11)$$

where I_{c1}, I_{c2}, I_{m1}, I_{m2} – amplitudes of constant and variable components of armature currents; φ_1, φ_2 – shift angles of currents variable components.

Power converter current is

$$i_\Sigma(t) = i_1(t) + i_2(t).$$

In case of equality of control actions frequencies we can compensate any harmonic of armature currents.

Compensation conditions for harmonic with number *m* according to (11) are

$$I_{m1} = I_{m2}; \quad \varphi_1 - \varphi_2 = \pi \ . \qquad (12)$$

So we get principles of designing of automatic compensation system of current variable component at power converter circuit [10, 14, 15]:

− actions frequencies of converters at excitation winding circuits must be equal;

− actions amplitudes must support equality of current effective value to rate value;

− amplitudes of basic harmonics of armature circuits currents must be equal to each other, and phase shift angles must qualify to condition $\varphi_1 - \varphi_2 = \pi$.

Basic requirements for control system are forming of optimal control law with support of minimum constant-sign value of power converter current and highest possible compensation of variable component of power converter current. Also important characteristics of control system are cost and implementation simplicity at mass tests of DCM.

Control parameters are effective value of currents of power converter, tested motor and compensator. These currents effective values defined under loading period. Presented at papers [10, 15] extremal system allows automatically define required quality factor and support it at target level (maximum or minimum).

The operating algorithm of control system of testing complex with compensating and loading modes is developed [10, 14].

The operating algorithm of compensating system with using electromechanical compensator at constant direction of power converter current and supporting minimum effective value of this current is presented on Fig. 2.

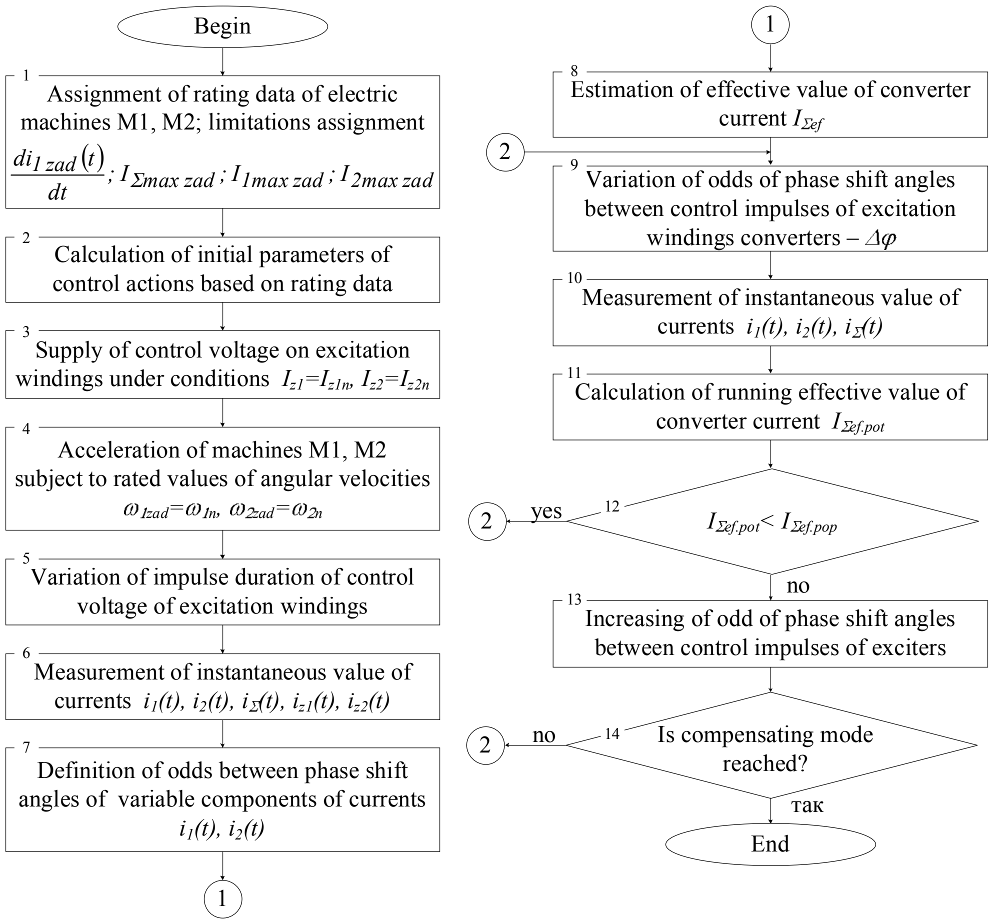

Figure 2 – Operating algorithm of control system at compensating mode

For definition of odds between shift angles of machine currents and for loading mode formation it is necessary to control following parameters: armature voltages and currents ($u_{a1}(i)$, $u_{a2}(i)$, $i_{a1}(i)$, $i_{a2}(i)$); angular velocities ($\omega_1(i)$, $\omega_2(i)$); excitation currents ($i_{z1}(i)$, $i_{z2}(i)$) of both electrical machines, and voltage and current of power converter ($u(i)$, $i_\Sigma(i)$), where *i* – corresponding moment of parameter measurement.

Using before repair parameters of electrical machines the variation limits of control voltages subject to elimination of overloads and emergency states are defined. This limits bases on derivative of motor maximum current, and on maximum values of motor, converter and compensator currents ($dI_{1\max}/dt$, $I_{\Sigma\max}$, $I_{1\max}$, $I_{2\max}$). Control actions based on ratings are calculated. The excitation circuits of electrical machines supplied by controlled transistor converters through current sensor. Using this controlled transistor converters the excitation currents of electrical machines are varying. Armature circuits through armature currents sensors connected to controlled thyristor converter with voltage controlled by sensor. The acceleration of both electrical machines subject to rated values of angular velocities $\omega_1 = \omega_{1n}$, $\omega_2 = \omega_{2n}$ under limitation of starting current carrying by assignment of constant excitation voltages and variation of output voltage of controlled converter at armature circuit. In this case we can use intensity controller or closed loop with limitation of dynamic current.

The forming of effective values of machines currents equal to rated values of currents $I_{z1} = I_{z\ 1n}$, $I_{z2} = I_{z2n}$ are received by variation of output voltages U_{zc1}, U_{zc2} of controlled converters at excitation winding circuits. Using linear increasing of impulse duration of control voltage ΔU_{z2} of compensator the equality of amplitudes of variable components of armature currents of both machines is reached. Using control of armature currents of both machines the instantaneous values of this currents are detected during (3…4)T periods of current variable component.

Phase shift angles of current variable components and phase odd between current vectors are calculated:

$$\varphi_1 = a\tan\left(I_{a1}/I_{b1}\right);\ \varphi_2 = a\tan\left(I_{a2}/I_{b2}\right);$$
$$\Delta\varphi = \varphi_2 - \varphi_1 = a\tan\left(I_{a2}/I_{b2}\right) - a\tan\left(I_{a1}/I_{b1}\right),$$

where I_{a1}, I_{b1}, I_{a2}, I_{b2} – orthogonal sine and cosine components of currents of tested motor and compensator defined by instantaneous values of currents measured at i time moments of loading period with general number of measurements N.

Under discrete measurement the orthogonal components of current are

$$I_c = \frac{1}{N}\sum_{i=1}^{n} I_i\ ;\ I_a = \frac{2}{N}\sum_{i=1}^{n} I_i\cos\left(i\Omega\Delta t\right);$$
$$I_b = \frac{2}{N}\sum_{i=1}^{n} I_i\sin\left(i\Omega\Delta t\right),$$

where Ω – basic frequency of variable component of armature current of tested machines.

The effective and mean values of power converter current of first harmonic are

$$I_{\Sigma ef} = \sqrt{\frac{1}{\mathrm{N}}\sum_{i=0}^{N} I_{\Sigma}\left[i\right]^2} = \sqrt{I_1^2 + I_2^2 + 2I_1I_2\cos\Delta\varphi}\ ;$$

$$I_{\Sigma ser} = \sqrt{\frac{1}{\mathrm{N}}\sum_{i=0}^{N} I_{\Sigma}\left[i\right]}\ .$$

The running odd between current vectors $\Delta\varphi$ and running effective value of armature converter current $I_{\Sigma ef.pot}$ are calculated using variation of phase shift angles of machine excitation voltage and controlling machine armature currents.

Running value of current $I_{\Sigma ef.\,\mathrm{pot}}$ compared to previous value $I_{\Sigma ef.\,pop}$. If condition $I_{\Sigma ef.\,\mathrm{pot}} < I_{\Sigma ef.\,pop}$ is true, phase shift between components of excitation voltages increased. So using variation of odd of phase shift of excitation voltages impulses of electrical machines we reach operating mode with minimum value of effective current of power converter.

Under increasing of phase odd $\Delta\varphi$ resultant vector of current approaches from maximum value $I_{\Sigma ef} = \sqrt{I_1^2 + I_2^2 + 2I_1I_2}$ at $\Delta\varphi = 0$ to minimum value $I_{\Sigma ef} = \sqrt{I_1^2 + I_2^2 - 2I_1I_2}$ at $\Delta\varphi = \pi$. Notably variation of excitation flux of compensator must be realized with support of opposite phases of variable components of compensator armature current and variable components of tested motor armature current.

The loading mode of tested motor carried as shown on Fig. 3.

Using increasing of amplitude of variable component of control voltage U_{z1}, U_{z2} of converters at excitation winding circuits we reach equality of effective value of tested motor current to its rated value. This equality reached by matching of odd $\Delta\varphi$ of phase shift angles with minimum and constant-sign value of current $I_{\Sigma ef}$ of converter at armature circuit. Under exceeding of specified limitations of armature current derivative $dI_{1\max}/dt < dI_1/dt$ and maximum value of currents of power converters of tested motor and compensator $I_{\Sigma\max\ \mathrm{zad}} < I_{\Sigma\max}$, $I_{1\max\ \mathrm{zad}} < I_{1\max}$, $I_{2\max\ \mathrm{zad}} < I_{2\max}$ the duration of control impulses of converters at excitation circuits of electrical machines are decreased.

At compensating mode the testing process of electrical machine is carrying out during competent time with measurement of machine electrical and mechanical parameters.

Formation of specified loading modes at open-loop cross-load system reached by actual parameters of repaired machine. Not always we can define these actual parameters before testing. Variation of actual parameters of electrical machine excites invalid definition of control laws. That excites inaccuracy of formation of required loading mode. Therefore it is necessary to design close-loop system with forming of optimal control laws [11, 14].

Basing on received principles and developed algorithms (Fig. 2, 3) the block scheme (Fig. 4) of control system with cross-load of DCM and automatic formation of loading mode with compensation of variable component of power converter current is synthesized [11, 15, 16].

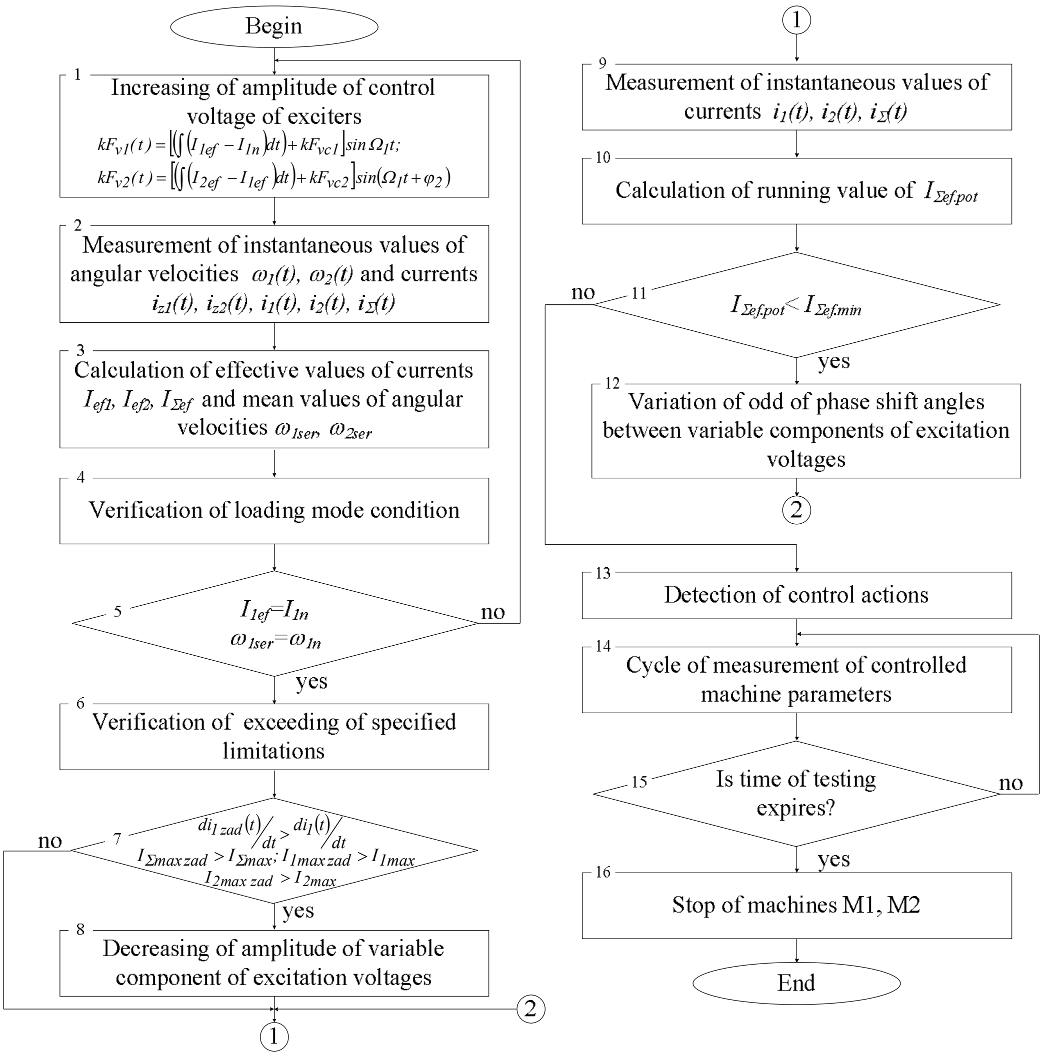

Figure 3 – Operating algorithm of control system at loading mode

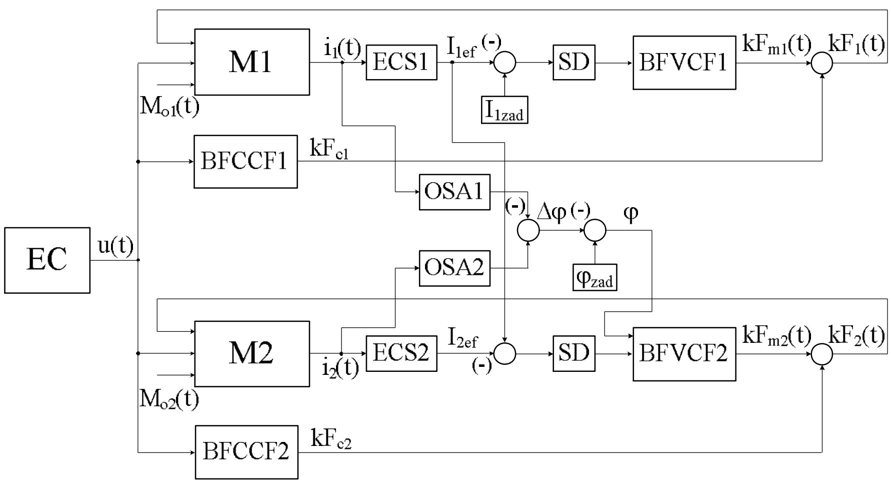

Figure 4 – Block scheme of control system of cross-load of DCM

Synthesized system in basic consists of blocks of flux variable component forming (BFVCF) and flux constant component forming (BFCCF) of tested motor and compensator. The structure of BFVCF is shown on Fig. 5. Block consists of comparator 5, adder 6, integrator I, scale amplifiers A1– A3, quantizer Q, basic frequency generators – FG and multiplier MP.

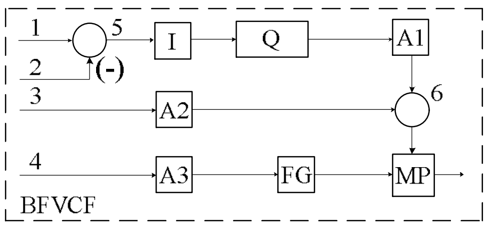

Figure 5 – Structure of BFVCF

Using control signals under conditions of loading mode forming we define: value of armature circuit voltage; constant value of magnetic flux of electrical machines; value of FG frequency.

Initial amplitude of input flux of FG is specified equal to $0{,}001kF_{zn}$ using scale amplifier. The constant components of flux are formed at BFVCF1 and BFVCF2.

Motor are accelerated to required angular velocity. Afterwards switch devices SD connects BFVCF. BFVCF1 forms loading mode (Fig. 2). BFVCF2 forms compensating mode (Fig. 3). As result of variation of amplitude of FG output signal value of excitation winding circuits currents are set up at levels:

$$i_{z1}(t)=I_{c1}+I_{m1}\sin\Omega t;$$

$$i_{z2}(t)=I_{c2}+I_{m2}\sin(\Omega t-\varphi),$$

where φ – shift angle of variable component of compensator excitation current.

Operating principle of BFVCF1 is following: at input 1 receives signal equal to rated value of tested motor current; at input 2 receives signal of effective value of current through effective current sensor ECS1; odd of signals of input 1 and 2 be received at input of integrator I; signal of integrator output receives at scale amplifier A1; scale amplifier A1, quantizer Q, scale amplifier A2 and adder 6 forms amplitude of magnetic flux variable component. Scale amplifier A3 forms frequency of FG. Amplitude of magnetic flux variable component increases until effective value of current I_{1ef} will be equal to its rated value.

BFVCF2 is operating on same algorithm as BFVCF1 with following deference: input signal 1 is signal if effective current of tested motor, and input signal 2 is signal of sensor of compensator effective current ECS 2.

Shift angle for compensating mode forms according to block scheme as shown on Fig. 6. Operating principle is following: at input 1 receives signal of instantaneous value of tested motor current; at input 2 receives signal of instantaneous value of compensator current; thereafter shift angles of variable components of compared currents are obtained using special blocks OSA1, OSA2; comparator 5 is calculating phase odd between current vectors; obtained signal adds to specified value φ_{zad} and formed signal receives on FG of BFVCF2.

The research is carry out under following conditions:

− voltage of armature circuits of electrical machines has constant value equal to rated value;

− moments of resistance to rotation are taken equal to zero;

− constant component of magnetic flux for each electrical machines defined as $kF_c = K_u U_n / \omega_n$ (accept $K_u = 0{,}9$);

− initial value of magnetic flux variable component of each electrical machines is taken equal to $kF_{v0} = 0{,}001kF_n$;

− initial value of shift angle φ_{zad} between variable components of currents of tested motor and compensator is taken equal to π.

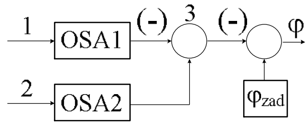

Figure 6 – Block scheme of forming of shift angle of magnetic flux variable component

Analysis of received results [11, 16] shows:

− we can get loading and compensating modes for considered cases under condition of equality of loading frequencies of electrical machines;

− shift angle of variable component of compensator excitation current for considered cases is equal to 180^{0};

− we can get forming of loading mode using nonreversive semiconductor converter for supply of armature circuits of electric machines under condition of equality of their powers;

− in the case then compensator power exceeds power of tested motor control system will decrease current consumption of power converter (at this case constant-sign current cannot be formed because idling current value of compensator exceeds value of effective current of tested motor $I_{2nx}>I_{1ef}$);

− defined possibility of loading and compensating modes forming of electrical machines with nonequal rated values of angular velocities and magnetic fluxes.

CONCLUSIONS. In the paper analysis of definition methods of control parameters of semiconductor energy converter at DCM testing complexes was carry out. Methods of control parameters calculation using mathematical model were considered. Thereafter we get following conclusions:

− using of mathematical apparatus is complicated, especially at loading mode forming with influence on excitation winding circuit;

− implementation of experimental design methods allows to calculate duration coefficients of control impulses of converters at excitation winding circuits of tested motor and compensator, but not allows to sufficiently obtain shift angle of control impulse of converter at excitation winding circuit of compensator;

− designed mathematical model of control system of direct current machines cross-load allows to calculate and match control parameters of semiconductor converters for forming of compensating and loading modes under electrical machines testing.

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ОПРЕДЕЛЕНИЕ ПАРАМЕТРОВ УПРАВЛЕНИЯ СИЛОВЫМИ ПРЕОБРАЗОВАТЕЛЯМИ ЭНЕРГИИ В КОМПЛЕКСАХ ДЛЯ ИСПЫТАНИЯ МАШИН ПОСТОЯННОГО ТОКА

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Рассмотрены вопросы расчета параметров управления силовыми полупроводниковыми преобразователями энергии для реализации нагрузочных режимов испытуемых машин постоянного тока. Рассмотрена блок-схема комплекса для испытания и проанализированы режимы нагрузки с воздействием на якорную цепь, на цепь обмотки возбуждения и комбинированном воздействии. Рассмотрены вопросы использования метода планирования эксперимента с целью построения регрессионной модели для определения параметров управления полупроводниковыми преобразователями энергии в цепи обмотки возбуждения. Раскрыты принципы построения системы автоматической компенсации переменной составляющей тока в цепи силового преобразователя. Приведены алгоритмы работы системы управления в режимах компенсации и нагружения. Рассмотрена блок-схема модели системы управления взаимным нагружением машин постоянного тока, на основании исследования которой сделаны выводы о возможности формирования режимов компенсации и нагружения.

Ключевые слова: испытательный комплекс, машина постоянного тока, преобразователь энергии, параметры управления, нагрузочный режим, режим компенсации.

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