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EVOLUTIONARY OPTIMIZATION OF DC MOTOR CONTROL SYSTEM

OPTYMALIZACJA EWOLUCYJNA UKŁADU STEROWANIA SILNIKIEM PRĄDU STAŁEGO

Abstract

The mathematical model of a DC motor control system's dynamic work with series impulse was designed. Control is performed by thyristor's ignition angle changing with doubling voltage. The parametric optimization was realized by genetic algorithm. The main genetic operators were crossover and mutation.

Keywords: genetic algorithm, individual, population, mutation, target function, DC motor

Streszczenie

Przedstawiono model matematyczny badania dynamiki układu sterowania silnika prądu stałego z wzbudzeniem szeregowym. Sterowanie zostało wykonane za pomocą zmiany kąta opóźnienia załączenia tyrystorów prostownika z podwajaniem napięcia. Optymalizacja parametryczna układu realizowana jest za pomocą algorytmu genetycznego. Głównymi operatorami genetycznymi wybrano krzyżowanie i mutację.

Słowa kluczowe: algorytm genetyczny, osobnik, populacja, mutacja, funkcja celu, silnik prądu stałego

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1. Introduction

All electric motors are divided into DC and AC motors. AC motors are controlled by a frequency converter. These devices are cotrolled by voltage supplying. These devices are cumbersome and greatly complicate the regulatory process. DC motors are much more comfortable regarding these criteria. So, they are widely used in a large amount of technical systems. Sometimes, other actuators besides the motor, such as electromagnetic relays are used. However, their application is limited as they perform only a switching action.

In this work a system is considered, in which a single-phase rectifier with a doubling of voltage is used. It serves as the voltage regulator, which can control engine speed and at the same time increase its maximum amplitude. The regulation occurs by the changing of the thyristor's opening angle. It leads to the output voltage's changing that feeds the motor. The motor voltage changing directly affects the speed of its rotation. Numerical values changing the system's parameters will change the dynamics of its work. So, selecting a certain value, it is possible to optimize the transient characteristics of the motor. This problem is called a parametric optimization. It is a key element of this work.

The combination of electric motor and regulated converter of AC voltage into DC voltage is called the electric drive. The electric drive is the electromechanical system. It consists of mechanical, converting, transmitting devices and control circuit. It is possible to differ a controlled electric drive, the parameters of which can be changed and uncontrolled. The most widespread type of controlled electric drive is an electric drive of DC voltage, in which the regulation process occurs by the changing of DC motor's average meaning. The example of controlled DC voltage is thyristor's converters. Such electric drives are called thyristor drives. The main requirements to an electric drive are the support of specified rotation speed, acceleration and minimum acceleration time.

The main technical parameters of the thyristor's controlled electric drives are nominal current and voltage. The nominal current of the thyristor's controlled electric drive must be larger than the nominal current motor. The nominal voltage of the motor must be smaller than the nominal voltage of the controlled drive by 5–10%, which provides the stock for speed regulation. The choice of the thyristor's controlled electric drive is executed depending on the technical task, in which voltage, current and speed is determined. It is possible to estimate quality of the device's work according to its electromechanical characteristics. The frequency's dependence on rotating moment is called motor's mechanical characteristic. These characteristics show that frequency of motor's rotation could be regulated by supply voltage. It is achieved by changing the kindling angle of the thyristor's voltage converter. So, we select the asymmetrical straightening scheme by doubling voltage.

The DC motor's design parameters have a large impact on its characteristic. It includes an active winding bearing and its inductance. Also it includes a moment of the motor's inertia. A special interest causes the dependence of angle speed of motors' rotation on time. A transitional process in the motor's racing time must be minimized. Such work's regime can be achieved only with optimal constructive motor's parameters.

The task of parametric optimization of the motor's control system predicates the search of parameters, which provides its stable standard. To achieve this aim it is necessary to implement its casual surplus with further estimation of motor condition. It gives an opportunity to achieve such a set of parameters, which will supply the stableness of its output characteristics. To achieve this it is necessary to use the genetic algorithm.

2. Analysis of publications

The implementation of the genetic algorithm can be found in different tasks. For example, in [1] it is proposed to use a genetic algorithm for the searching of differential equations' marginal condition. It is balanced to a two-point marginal problem's solution. The hybrid method was used, which combines two algorithms. It is a genetic and classical algorithm. In [2] the genetic algorithm was used to reduce the power consumption of mobile robots. The wheels are moved by DC motor. Power consumption's reduction was achieved during the robot's moving on uneven area. The parametric optimization of the traction drive is shown in the work [3], where parallel data processing has been used. It gives an opportunity to reduce accounting time. The genetic algorithm gives good results for nonlinear system's optimization [4]. Such an approach gives an opportunity to find a global optimum. The fields' analysis problem was explored with a genetic algorithm. The large dimension of this task, which was caused by using the method of final elements, gave an opportunity for authors to find a new decision. It is proposed to use the parametric models of lower order to account for the target function. In [6] the brushless micro motor MBDCM with structural genetic algorithm using was explored (RSGA). It combines the advantages of simple genetic algorithm and optimal structural genetic algorithm of optimal control. The calculations are confirmed by experimental results. In [7] the original idea, where a genetic algorithm was used for optimization of material's division in electric machines was suggested. The optimization of stator's jags' topology in the DC motor was executed. It reduced the pulsation of rotation moment without decrease of average rotation moment. In [8] the scheme of the motor's disturbance compensation was suggested. In conjunction with a classic feedback controller it improves the motor's reaction to micro shunting. The controller's parameters are selected by genetic algorithm. In [9] an algorithm of dynamic coding (DEAS) was shown as an alternative to the genetic algorithm. The digital modeling of an asynchronous motor's start is examined. However, this approach has the limit tasks' class. It is possible to select the parameters of the DC motor's regulation using the genetic algorithm. The microcontroller was used as a PID- regulator. The preparation of the regulator's parameters is executed by genetic algorithm. To sum up, it is possible to make the conclusion that genetic algorithms give good results during optimal parameters of control systems selecting.

3. The mathematical model of control system

The investigated system includes such two elements as an asymmetrical monophase rectifier with double voltage multiplication and DC motor with wound series. The rectifier includes two thyristors, which are controlled by the separate scheme. The dynamic equation of these elements is shown in rotation.

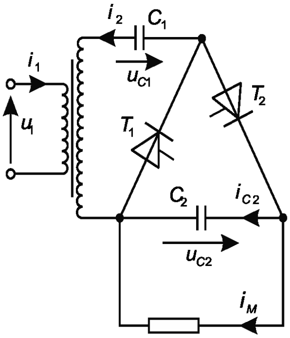

Fig. 1. The principal scheme of asymmetrical rectifier with double voltage multiplication

The asymmetrical monophase rectifier with double voltage multiplication. In Fig. 1 the principal scheme of rectifier is shown. Voltage doubling occurs in such a way. Using doubling voltage on the transformer's exit the thyristor T_1 and capacitor C_1 are charged. The change of polarity of output voltage leads to a drop of the thyristor T_1 opening of thyristor T_2. In this period the output transformer's and capacitor's voltage would have the same direction. Then the capacitor C_1 begins to charge. This sum would be nearly twice larger than output voltage. So, double voltage would be added to capacity. Thyristor's modeling has been executed using the scheme of ideal key. So, this scheme would have a changeable structure of electric circuit. The modeling of these schemes was executed by additional binary variables introduction in to device's dynamic equation. It assumes the values 0, 1. Zero value corresponds to closed valve's condition and the value 1 corresponds to open valve's condition. It gives the opportunity to describe all combinations of open and closed valves by single equations system. It would have three combinations.

The final equations system for monophase rectifier with double voltage multiplication was written [12]:

$$\frac{dX_1}{dt} = BZ(t), \tag{1}$$

where:

$X_1 = [\psi, i_2, u_{C1}, u_{C2}]^T$ – the matrix of rectifier's variable condition;

$Z(t) = [u_1 - r_1 i_1,\ \ u_{C2}k_2 - u_{C1} - r_2 i_2,\ \ i_2,\ \ -k_2 i_2 - u_{C2} / R_H]^T$ – time functions' vector;

$B = \mathrm{diag}[M,\ \ C_1^{-1},\ \ C_2^{-1}]$ – coefficients' matrix;

$$M = \begin{bmatrix} g_1 & g_2 \\ a_{21} & a_{22} \end{bmatrix},\ g_1 = \frac{\alpha_1}{\alpha'' + \alpha_1 + (k_1 + k_2)\alpha_2},\ g_2 = \frac{(k_1 + k_2)\alpha_2}{\alpha'' + \alpha_1 + (k_1 + k_2)\alpha_2},$$

$a_{21} = -\alpha_2 g_1,\ \ a_{22} = (k_1 + k_2)\alpha_2(1 - g_2).$

These physical values' denominations were used here.

ψ – the transformer's flux linkage;

i_1, i_2 – the current of primary and secondary winding;

u_1 – the voltage of the transformer's power;

u_{C1} – the capacitor's voltage C_1;
u_{C2} – the capacitor's voltage C_2;
r_1, r_2 – the resistanceof primary and secondary transformer's windings;
R_H – the load impedance;
α'' – the inverse differential inductance;
α_1, α_2 – the inverse inductance of primary and secondary windings' scattering of transformer;

The inverse differential inductance α'' is determined by magnetic curve $\varphi(\psi)$ as a derivative of:

$$\alpha'' = \partial\varphi(\psi)/\partial\psi \cdot \tag{2}$$

It is necessary to add the dynamic equation (1) by the conditions of valves' open and close moment. These conditions determine time moments, when binominal variables k_1, k_2 change their meaning.

If two valves are closed ($k_1 = k_2 = 0$), it is necessary to control its opening conditions:

$$-d\psi / dt - u_{C1} \geq 0\,, \tag{3}$$

$$d\psi / dt + u_{C1} - u_{C2} \geq 0\,. \tag{4}$$

If the condition (3) is executed, the thyristor T_1 will be opened ($k_1 = 1$). If the condition (4) is executed, the thyristor T_2 will be opened ($k_2 = 1$).

If the thyristor T_1 is opened ($k_1 = 1$), but T_2 is closed ($k_2 = 0$) the condition of closing thyristor T_1 will be checked.

$$i_2 = 0, \quad \frac{di_2}{dt} < 0\,. \tag{5}$$

If the condition (5) is executed, the thyristor T_1 will be closed ($k = 0$).

If the thyristor T_1 is closed ($k_2 = 0$), but T_2 is opened ($k_1 = 1$), the condition of the closing thyristor T_2 will be checked.

$$i_2 = 0, \quad \frac{di_2}{dt} > 0 \cdot \tag{6}$$

If condition (6) is executed the thyristor T_2 will be closed ($k_2 = 0$).

DC motor with series wound. It attitudes to electromechanical devices and it is described by differential equations' system of fourth order.

$$\left.\begin{aligned} \frac{di_A}{d\tau} = S_A u_A - T_A u_F + E_A, \quad \frac{di_F}{d\tau} = -T_F u_A + S_F u_F - E_F\,,\\ \frac{d\omega}{d\tau} = (c\Phi i_A - M_O)/J, \quad \frac{d\gamma}{d\tau} = \omega, \end{aligned}\right\} \tag{7}$$

where:

$S_A = 1/(L_A + L_{AF}L_{FA}/L_F), T_A = S_A L_{AF}/L_F, E_A = S_A(L_{AF}r_F i_F/L_F - c\omega\Phi - \Delta u - r_A i_A),$
$T_F = S_A L_{FA}/L_F,\; S_F = (1 - L_{FA}T_A)/L_F,\; E_F = (L_{FA}E_A + r_F i_F)/L_F.$
L_A – the summary inductance of series anchor's circle;

L_F – the inductance of excitation winding;
L_{AF}, L_{FA} – the mutual inductance of an anchor's circle and an excitation's circle;
r_A, r_F – the active supports of an anchor's circle and an excitation's circle;
ω, γ – the angular velocity of DC motor's angle rotation;
Φ – the magnetic flow of the motor;
c – the constructive constant motor's anchor;
Δu – the voltage fall in brush contact;
J – the moment of motor's rotor inertia;
M_O – the moment of resistance;
u_A, u_F – the voltage of the anchor's circle and excitation's circle nourishment.

In compensated motors the consideration of a magnetic conductor's saturation could be executed approximately by magnetic curve.

In unsaturated motor it would be:

$$\Phi = L_F i_F / w_F, \tag{8}$$

To receive the DC motor's equation with series wound the equation (9) must be added by these conditions:

$$i_A = i_F = i_M, \;\; u_M = u_A + u_F, \tag{9}$$

If the (7) and (9) is solved the DC motor's equation with series excitation will be received.

$$\frac{di_M}{d\tau} = C_A u_M + C_F, \quad C_A = \frac{S_A S_F - T_A T_F}{T_A + S_A + T_f + S_F}, \; C_F = \frac{E_A(S_F + T_F) - S_A E_F - T_A T_F}{T_A + S_A + T_f + S_F}. \tag{10}$$

Now it is necessary to combine the motor's equation and the equation of asymmetric rectifier with double voltage. In equation (10) it is necessary to replace the voltage of nourishment u_M by the output rectifier's voltage u_{C2}. Then, the equation (10) will be receive the form:

$$\frac{di_M}{d\tau} = C_A u_{C2} + C_F. \tag{11}$$

In the rectifier's equation the current of capacitor C_2 is determined by this formula:

$$i_{C2} = -k_2 i_2 - u_{C2} / R_H. \tag{12}$$

In this expression the current's load is determined as a u_{C2} / R_H. Because the rectifier is loaded by the motor's windings, the current's load will be equal to motor's current i_M. It means that expression (12) will get a form of:

$$i_{C2} = -k_2 i_2 - i_M. \tag{13}$$

So, in formula (1) the vector of time functions $Z(t)$ will be:

$$Z(t) = [u_1 - r_1 i_1, \;\; u_{C2} k_2 - u_{C1} - r_2 i_2, \;\; i_2, \;\; -k_2 i_2 - i_M]^T. \tag{14}$$

4. Optimal parameters of selection using the genetic algorithm

The GA belongs to the class of evolutional algorithms. It can be used for solving optimization tasks and modeling, in which the method of consecutive casual selection, combination and variation of researched parameters is executed. It is reached by special mechanisms, which are similar to biological evolution. At the base of each GA the procedures of natural selection and heredity are filled. The evolutional principle where the most adapted survive is used. It greatly differs from classic parametric optimization algorithms. For example, the task can be solved using the simple number's combination but it requires the large amount of calculations. The second classical approach is the method of gradient descent. It has a large rapid performance, but usually it attains to local solution. Instead of this, the GA always leads to global optimum and requires much lover amount of computations than the method of simple computation.

The GA's universality means that it is not connected with the nature of investigated algorithm. In the process of work it needs each chromosome's estimation, which will mean it accommodation. During selection the chromosomes with the highest estimation are chosen. So, it reproduces more often than chromosomes with lower estimation. New chromosomes' reproduction occurs using a recombination of parent's chromosomes and gene. So, the new gene's combination with its new characteristic appears. In reproduction the operations of crossover and mutation are used. Interbreeding is the creation of new chromosomes using a recombination of parent's gene. Mutation occurs only the changes in some chromosomes.

The GA's main meaning is the fitness function. Sometimes it is called the target function. In our case it is built as a difference between desirable standard output signal and real. So, the object's parameters are combined, the fitness function reaches the minimum meaning. In each generation each individual is estimated using fitness function. Then, the next generation is created, which is draws the input signal to desirable one.

If two genetic crossover operators and the mutation were compared the last one would play the secondary role. For this reason, a crossover operator can always be used, but mutation never can be used. At the first stage of crossing the couples of the chromosome are chosen from the parent's population. It is a temporary population, which consists of chromosomes, chosen by selection. It is appointed to future transformations by crossover operators and mutation. The new population is formed. At this stage the parent's population chromosomes are coupled. It is implemented by an accidental method according to the expectancy of crossover. Then, for each couple the genetic position is charged, which determines the point of the crossover. If each parent's chromosome consists of N genes, it is evidently that the point of crossing NC_C is a natural number, which is less than N. That's why the crossover point fixation becomes an accidental choice of number from interval [1, N-1].

In the result of a parent's chromosome couple the pair of following descendants are formed: 1) its chromosome from 1 to N_i consists of first parent's genes but in the position from N_{i+1} to N consists of second parent's gene; 2) its chromosome from 1 to N_i consists of second parent's genes but in the position from N_{i+1} to N consists of the first parent's gene. Mutation operator with p_m probability changes the gene meaning in chromosome on reverse (from 0 to 1 and wise versa). For example if in chromosome [111011110101] the gene in the 9th position can be mutated, so its meaning, which is equal to 0, will be changed on 1. It leads to chromosome [111011111101] creation. The mutation probability is more than small.

The classic GA consists of these stages. Firstly the primary population is generated. It is a set of the task's solution. Usually it is executed by accidental way. Inside this population the reproduction must be modeled. For this task several individual's pairs are chosen accidentally, the crossover between chromosomes is executed in each couple but newly received chromosomes are placed in the new generation population. In the GA the leading principle of natural selection is saved. If the individual is more accommodated, so with the larger possibility it will take a part in crossover. Now the mutation is modeled in such accidentally chosen individuals of the new generation, which genes are changed. Then, the old population is partially or fully destroyed and we pass to the new population's examination. In mostly GA realization the next generation population includes such an amount of persons as in primary realization but taking into the results of selection generally its accommodation is larger.

The chromosomes' accommodation estimation in population is executed using a fitness function. It is accounted in each chromosome in population. If the meaning of this function is larger the quality of chromosome will be higher. Fitness function's form depends on character of solved task. It is predicated that fitness function always takes only positive meanings and, except of it for optimization tasks' solving this function must be minimized. The determination of genetic algorithm stopping condition depends on its specific using. In optimization tasks it is necessary to determine the accuracy which will be used to achieve fitness function's minimum meaning, than GA will be stopped. The algorithm stoppage can be occurred if its execution doesn't lead to an improvement of the achieved task. The algorithm can be stopped after a determined iteration amount executing. In the GA the stage of selection is extracted, where the individuals, which have been received the largest meaning of fitness function from current population, are selected from the current population and inserted to THE parents' population. The identification of stopping genetic algorithm condition depends on its specific usage. In optimization tasks it is necessary to know the accuracy, by which the minimal meaning of fitness function can be reached and the GA algorithm will be stopped. Algorithm stoppage can be occurred if its execution doesn't lead to improving achieved meaning. The algorithm can be stopped after the execution of the adjusted amount of iteration. In the GA the selection stage in which the individuals are chosen and selected from current population and included to parents' population with the largest meaning of fitness function are extracted. At the next stage, sometimes called evolution the genetic operators of crossover and mutation are used, which executes the recombination of genes in chromosomes.

5. The results of computer simulation

Based on received mathematic model of control system the program for parametric optimization of an investigated object was developed. The mathematical model is described by the system of six nonlinear differential equations. The equations' data are solved by the Runge-Kutta method of fourth stage of accuracy with constant stage of iteration. This method gives an opportunity to solve differential equation with established primary conditions. For this task the primary conditions is established as zero. It gives an opportunity to estimate the dynamic of systems work. The asymmetric rectifier with double is performed as control element. The rectifier's voltage is determined by expression $u_1 = 311\sin(100\pi t)$ V.

The calculations were executed using such transformer's parameters: r_1 = 2.0 Ohm; r_2 1.6 Ohm; $\alpha_1 = \alpha_2$ = 270 H^{-1}; C_1 = 2.0 mF, C_2 = 2.0 mF. The magnetization curve is approximated by expression with accounting formula:

$$\varphi(\psi)=\begin{cases} a_1\psi, & |\psi|>\psi_1, \\ S_3(\psi), & \psi_1\le|\psi|\le\psi_2, \\ a_2\psi-a_0, & |\psi|>\psi_2, \end{cases} \tag{15}$$

where:
a_1 = 1 H^{-1}; a_1 = 52 H^{-1}; a_0 = 29.4 A; ψ_1 = 0.15 W; ψ_1 = 0.7 Wb; $\varphi(\psi_1)$ = 0.15A; $\varphi(\psi_2)$ = 7.0 A; $S_3(\psi)$ is a cubical spline. It is necessary to make a mark that $\alpha''(\psi_1) = a_1$, $\alpha''(\psi_2) = a_2$.
Motor's parameters: L_A = 4.67 mH; L_{FF} = 75.8 H; r_A = 0.0332 Ohm; r_F = 45 Ohm; $L_{AF} = L_{FA}$ = 0.03 mH; M_O = 75 N·m; J = 0.2 N·m·s^2/rad; c = 70.8 N·m/(Wb·A).

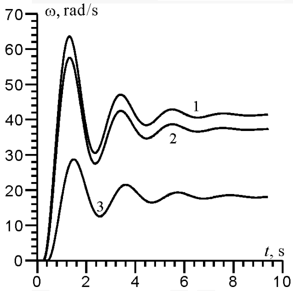

Fig. 2. The transient process' curves of motor's angular speed for ignition's angle 0° (curve 1), 30° (curve 2), 90° (curve 3) before optimization

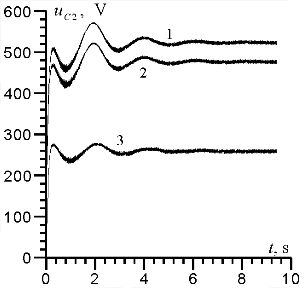

Fig. 3. The transient process' curves of output rectifier's voltage for ignition's angle 0° (curve 1), 30° (curve 2), 90° (curve 3) before optimization

Rectifier's capacitors impact on DC motor's dynamic was investigated. Firstly the accounts for appointed capacitor's capacitance were executed, it means that C_1 = 2.0 mF, C_2 = 2.0 mF. The results for a different ignition's angle 0°, 30°, 90° of thyristors were received using described data. In fig. 2 the transient process' curves of motor's angular speed for ignition's angle 0° (curve 1), 30° (curve 2), 9° (curve 3) 0° were used. To compare these results it is possible to make such conclusions. These received curves have a similar dynamic. It has a significant overshoot and quickly damped fluctuations. The difference is a constant speed meaning. For angle 0° (curve 1) the constant meaning of angle speed is equal to 41.2 rad/s, for angle 30° (curve 2) 37.2 rad/s, but for angle 90° (curve 3) 27.5 rad/s. In all cases the transient process is finished after 10 s. In all cases the overshoot is not larger than 55% from the constant meaning. In fig. 3 The transient process' curves of output rectifier's u_{C2}voltage for ignition's angle 0° (curve 1), 30° (curve 2), 90° (curve 3) are shown. These dependences include pulsations, which are connected with the process of rectification. In fig. 3 the transient process' curves of output rectifier's voltage for ignition's angle 0° (curve 1), 30° (curve 2), 90° (curve 3) are shown. In stable routine this voltage has constant and variable part. Moreover, the changeable part isn't larger than 3% of constant.

Using genetic algorithm we selected the optimal meaning of a capacitor's capacitance for different ignition's angle. In fig. 4 the the transient process' curves of motor's angular speed for ignition's angle 0° (curve 1), 30° (curve 2), 90° (curve 3) are shown. The meanings of the capacitor's capacitance C_1 = 0.121 mF, C_2 = 0.61 mF (curve 1), C_1 = 0.104 mF, $C_2$0.1422 mF (curve 2), C_1 = 3.88 mF, C_2 = 0.98 mF (curve 3). So, it is possible to optimize the transient process only for a small ignition's angle.

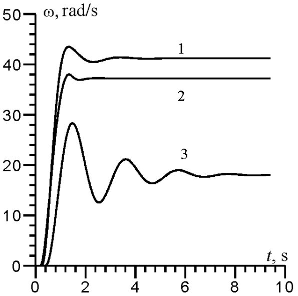

Fig. 4. The transient process' curves of motor's angular speed for ignition's angle 0° (curve 1), 30° (curve 2), 90° (curve 3) after optimization

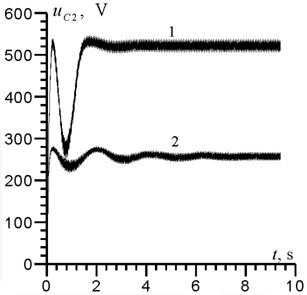

Fig. 5. The transient process' curves of output rectifier's voltage for ignition's angle 0° (curve 90° (curve 2) after optimization

For ignition's angle 0° (curve 1) the transient process has a small amount of overshoots. The best result has an ignition's angle 30° (curve 2). It has the smallest overshoot and the shortest transient process (< 2.5 s). If the ignition's angle becomes larger the quality will decrease but the overshoot and transient process will increase. It is not possible to find the optimal meanings of capacitor's capacitance. In Fig. 5 the transient process' curves of output rectifier's u_{C2} voltage for ignition's angle 0° (curve 1), 90° (curve 2) The result was received by the same data exploration as in Fig. 4. In comparison with the previous example (Fig. 3) the amount of changeable parts has been increased. For curve 1 it is not larger than 7% and for curve 2 it is < 10%.

This rectification scheme gives an opportunity to change a rapidity of motor's rotation using capacitor's capacitance alteration. Moreover, the ignition's angle can be equal to zero. The capacitor's capacitances were determined by genetic algorithm.

In Fig. 6 the transient process' curves of motor's rotation speed for constant meanings ω_{fixed} = 5 rad/s, C_1 = 53.6 mF, C_2 = 32.14 mF (curve 1), 2) ω_{fixed} = 10 rad/s, C_1 = 64. mF, C_2 = 42 mF (curve 2), 3) ω_{fixed} = 20 rad/s, C_1 = 72 mF, C_2 = 100. mF (curve 3), 4) ω_{fixed} = 30 rad/s, C_1 = 85 mF, C_2 = 355 mF (curve 4), 5) ω_{fixed} = 40 rad/s, C_1 = 113 mF, C_2 = 495 mF (curve 5) were shown. The appropriate curves of transient process of output rectifier's u_{C2} voltage is shown on Fig. 7.

To compare the results for the zero ignition's angle in Fig. 6 it is possible to make this conclusion. It is possible to select a capacitor's capacitance for all constant meanings of motor's speed ω_{fixed}. Furthermore, the overshoots are mostly absent and a time of transient process isn't larger than 2.5 s. The manipulation of an ignition's angle (Fig. 4) reaches the worse results and it needs the usage of appropriate regulators.

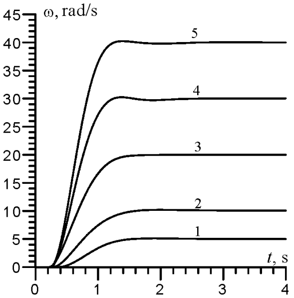

Fig. 6. The transient process' curves of motor's angular speed for constant meaning $\omega_{\text{fixed}} = 5$ rad/s, (curve 1), 10 rad/s (curve 2), 20 rad/s (curve 3), 30 rad/s, (curve 4), 40 rad/s, (curve 5)

In Fig. 7 transient process' curves of output rectifier's voltage u_{C2} for constant meaning 1) $\omega_{\text{fixed}} = 20$ rad/s (curve 1), 2) $\omega_{\text{fixed}} = 30$ rad/s (curve 2), 3) $\omega_{\text{fixed}} = 40$ rad/s (curve 3).

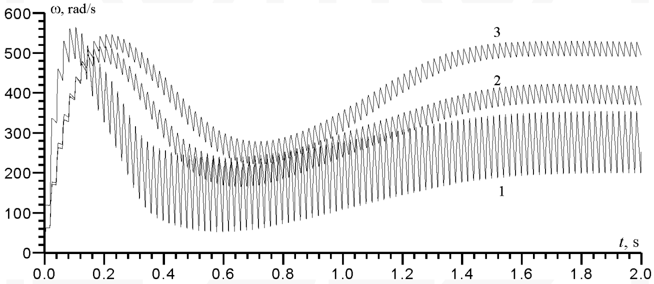

Fig. 7. The transient process' curves of output rectifier's voltage for constant meaning ω_{fixed} 20 rad/s (curve 1), 30 rad/s (curve 2), 40 rad/s (curve 3)

In comparison with the previous regime (Fig. 5) the amplitude of the changeable part is larger. For $\omega_{\text{fixed}} = 20$ rad/s (curve 1) it consists in 28% of constant part. Moreover, this system is stable enough. The change of the capacitor's capacitance and the moment's load doesn't exceed the stable limit.

It is possible to control an angular motor's speed changes to one of capacitor's capacitance. The results of analysis shows that it is more efficient to change capacitor's capacitance C_1 if the capacitor's capacitance will have a stable meaning $C_2 = 0.2$ mF. In Fig. 8 the calculated dependence of constant meanings of angle motor's speed ω_{fixed} on capacitor's capacitance C_1 is shown. It is possible to separate an area from 0.04 mF to 15 mF, where the angle motor's speed changes from 2 rad/s to 40 rad/s. The following capacitor's capacitance increase will not lead to significant increase of angle speed. In Fig. 9 the curves of transient process of motor's rotaiting speed for $C_1 = 0.05$ mF (curve 1), $C_1 = 0.07$ mF (curve 2),

C_1 = 0.13 mF (curve 3) are represented. In all cases the time of transient process isn't larger than 3.5 s. Overshooting is observed if the angle speed will have a maximum meaning. So, there curves have a very good dynamic characteristics and it is recommended to use the capacitor's overshoot for these schemes.

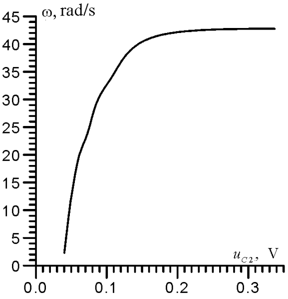

Fig. 8. The calculating steady-state values meaning's dependence of angle motor's speed ω_{fixed} on capacitor's capacitance C_1

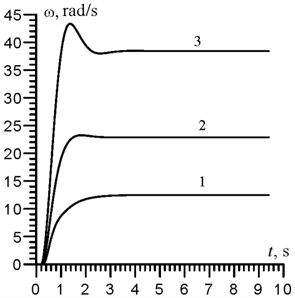

Fig. 9. The transient process' curves of motor's rotation speed C_1 = 0.05 mF (curve 1), C_1 = 0.07 mF (curve 2), C_1 = 0.13 mF (curve 3)

6. Conclusions

The mathematical model of control system of an angle DC motor's speed was represented. The parametric optimization of the capacitor's capacitance for different ignition's angle of thyristor's was executed. Optimization works only for small ignition angles and if it will be increased the dynamic picture of transient process becomes worse. It was proposed to select capacitor's capacitance for angle motor's speed overshooting instead of ignition's angle changing. Moreover the control's quality is provided by a wide diapason of angle speed unless 40 rad/s. In this work it is approved that it is possible to select a constant meaning of capacitance C_2 and to execute the controlling only by change the capacitance C_1. In all concrete cases it is necessary to define what is more easy to realized, the change of ignition's angle or capacitor's capacitance. The advantages of the last approach are better for a dynamic system's characteristics.

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