Energy-efficient control of a multi-section supercapacitor power supply of an electric drive

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Abstract. A method for synthesizing the control laws of a multi-section supercapacitor power supply of an electric drive is developed. The synthesized control law for an electric drive realizes the prescribed motion and minimizes the required capacitance of the power source. It is achieved through optimal disconnection and connection to the power line of the drive at designated times of one of the power supply sections. Reduction of the required capacitance of the power supply is achieved through a fuller discharge of some of its sections in motion conditions requiring a low level of electrical voltage and saving high voltage in other sections for the respective motion conditions. A mathematical formulation of the problem and a method of its solution is proposed. An example of the implementation of the proposed method is considered.

1 Introduction

Currently, electric drives with capacitor power supply (CPS) are widely used in industrial applications. Electric energy in such power supplies is stored in conventional capacitors and/or supercapacitors (ultracapacitors). Capacitors in the CPS can be periodically or continuously recharged, but when the drive performs energy-intensive motions, the role of the charging line is negligible, the main part of the energy in the drive comes from the capacitors.

Let us consider a class of problems assuming that the CPS must provide the energy necessary for the prescribed (programmed) motion of the electric drive for a given finite time interval. This class includes, for example, some tasks of robotics, the tasks of power supply for the electric vehicle cyclically moving along the designated route with a specified recharge point, the tasks of opening and closing valves on pipelines using electric drives powered by CPS.

CPS can be structurally divided into sections, with each containing several electrically connected capacitors and/or supercapacitors. This type of CPS is called multi-section capacitor power supply (MCPS). The choice of the capacitance of the sections and their number is carried out on the basis of design considerations and known energy costs for the realization of the assigned motion. The electrical connections of the MCPS sections to each other and to the power line of the drive are traditionally considered fixed.

The capacitance of the MCPS required for the implementation of the prescribed motion of the electric drive can be reduced by connecting of one of the MCPS sections to the power supply line at pre-scheduled times. Reduction of the required capacitance in this case is due to the possibility of more complete discharge of the MCPS sections in motion conditions requiring low voltage level and saving of high voltage charge for the respective motion conditions, which may be only in one section or a few MCPS sections.

Control laws for electric drives, which take into account the possibility of optimal disconnection and connection to the power line of one of the MCPS sections, lead to the increase of the energy efficiency of the considered drives, reduction of capacitance and, as a consequence, weight, size and cost of MCPS.

The topic of energy efficiency of electric drives with an autonomous power source is given considerable attention in modern scientific literature. In the paper [1] an adaptive energy-efficient control is developed for planar motion control of electric ground vehicles with four in-wheel electric drives. The article [2] presents a plug-in hybrid electric vehicle energy management control strategy that aims to improve the real energy usage efficiency. In the publication [3], the authors consider the possibility of increasing the energy efficiency of actuators based on the use of the load torque predictor in the drive control law. The paper [4] describes a supervisory energy efficiency control strategy for electrical energy transfers in multisource renewable energy systems. In the paper [5] an efficient energy-management system for a hybrid electric vehicle, using ultracapacitors and neural networks, was developed. In the publication [6], in order to improve energy efficiency, the authors propose design and new control of DC/DC converters to share energy between supercapacitors and batteries in hybrid vehicles. The article [7] considers the problem of energy-efficient coordinated use of such energy sources as electric batteries, ultracapacitors and fuel cells in the onboard energy-storage system of the vehicle. The paper [8] describes the energy-efficient application of batteries and

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ultracapacitors in electric energy storage units for hybrid-electric vehicles.

However, the available literature on the subject, despite the considerable interest in the topic of energy efficiency of electric drives with an autonomous power source, does not provide methods of synthesis of the above-mentioned control laws. This fact makes the development of such methods a necessity.

2 Formulation of the problem

We specify and mathematically describe the problem of synthesizing the control law of an electric drive, which assumes a rational shutdown and connection to the power supply line of the drive of one of the MCPS sections.

Let us assume that the motion of the drive output link on a limited interval of time is given, i.e., we assume a known function $\alpha^*(t)$, $t\in[0,T]$, where α^* is the coordinate of the output link of the drive, t time, T the upper boundary of the time interval.

Along with the motion program, we shall assume that the law of variation of the load torque $M(t)$ exerted on the motor shaft is given.

We will consider drives with DC motors with independent excitation. The dynamics of this motor is given by the following differential equations:

$$di/dt=(u-iR-\omega C_e)/L, \quad (1)$$

$$d\omega/dt=(iC_m-M)/J, \quad (2)$$

$$d\varphi/dt=\omega, \quad (3)$$

where i is the current in the motor winding; U voltage across the motor winding; R, L resistance and inductance of the rotor winding; ω, φ rotational speed and angular position of the motor rotor; C_e back EMF constant; C_m motor torque constant; J is the moment of inertia of the moving parts of the drive transposed to the motor rotor.

The mechanical transmission (gearbox) in the drive system converts the rotation of the motor shaft into a movement of the drive output shaft. The following equality holds:

$$\alpha=\varphi/k_g, \quad (4)$$

where α is the linear or angular coordinate of the output link of the drive (angle of rotation or linear travel depending on the type of drive), k_g gear ratio.

MCPS is divided into several sections. The MCPS section represents several permanently connected capacitors. The capacitance of the section is denoted by C_j, j=1,n. The number of sections n is assumed to be given. The maximum voltage of the charged MCPS section should not exceed the value of U_{max}.

At any one time, only one MCPS section must be connected to the drive power line. It is possible to disconnect and connect any section of the MCPS to the power line. At this time the voltage in the supply line is equal to the voltage of the MCPS section connected to it.

The voltage of the j-th section of the MCPS $U_j=q_j/C_j$, where q_j - electric charge of the j-th section. In the differential form, we get: $dU_j/dt=dq_j/dt(1/C_j)$, or

$$dU_j/dt=i/C_j, \quad (5)$$

where i - discharge current, in the considered problem equal to the current in the armature winding of the drive motor.

Electronic switches in the electric drive control system allow to disconnect and connect the anchor winding of the motor to the supply main with a switching polarity determined by the sign of the control signal ν, i.e.

$$u=U_j\,\mathrm{sign}(\nu),\ j(t)\in\{1,\dots,n\}, \quad (6)$$

where ν - is the signal, that determines the polarity of connecting the motor winding to the power line; sign($\cdot$) is a sign function, takes values from the set {-1, 0, + 1} in accordance with the sign of its argument.

Without a significant loss of generality, we specify electric drive control law as follows. In order to minimize the deviation of the realized $\alpha(t)$ from the desired $\alpha^*(t)$ law of motion, the value of ν at each moment of time will be chosen as follows:

$$\text{if } (\alpha^*-\alpha)+(\omega^*-\omega)\kappa>0, \text{ then } \nu=+1, \text{ otherwise } \nu=-1, \quad (7)$$

where κ is a constant (speed feedback coefficient).

The system of equations (1-7) is a mathematical description (model) of an electric drive with a multi-section controlled source of power. In it, equations (1-5) describe the control object, and equations (6, 7) - control law.

For the electric drive described by the system of equations (1-7), it is required in the control law (6, 7) that the function $j(t)$ and the coefficient κ must be determined to provide a sufficiently accurate implementation of the prescribed motion $\alpha^*(t)$, $t\in[0,T]$ of the drive output shaft with the minimum total capacitance of the MCPS sections.

3 Method of synthesizing

The formulated problem of synthesizing the control law does not allow for an exact analytical solution. Therefore, the following numerical method for finding approximate solutions to the problem under consideration is proposed.

The proposed method is based on specifying a finite set of time moments, in which the values of the control function $u(t)$ can change. Thus, the desired control law $u(t)$ is approximated by a function that changes values at certain instants of time from a given finite set. In this case, the specified time sampling does not extend to the other variables. As a result, the problem reduces to analyzing a finite set of control law variants.

A significant part of control law variants is excluded from the subsequent analysis based on the application of simple logical rules, set out below. For the next analysis version of the control for the simple analytical dependencies found, the optimal values of the capacitance of the sections and the total required capacitance of the source are calculated.

The computationally simple dependencies and logical rules allow you to quickly analyze a large volume of possible control options. As a result, among all possible control law variants, the optimal variant is identified, to which the minimum required capacitance of the source corresponds. In a more detailed presentation, the proposed method is reduced to performing the following actions.

1. Through the solution of equations (1)-(4), the inverse problem of dynamics [9, 10] is solved, and functions $u^*(t)$, $i^*(t)$, $t\in[0,T]$ are found, which determine the values of voltage and current in the motor winding for each moment of time, corresponding to the given motion of the output link of the drive $\alpha^*(t)$ and the law of change moment of the load force $M(t)$.

2. The time interval $[0,T]$ is divided into N equal intervals of length Δt, hereinafter referred to as time step. The time moment corresponding to the beginning of the k-th time sample ($k = 1, ... N$,) is denoted by t_k.

For each time sample, we assign the MCPS section number that is connected to the drive power line for the entire duration of the given time step. As a result, the value of the vector s consisting of N components is determined. The k-th component of this vector s_k takes values from the set $\{1, ..., n\}$, thereby determining the number of the MCPS section connected to the power line during the k-th time step.

The vector s contains for each instant $t\in[0,T]$, the values of the control variable j in the expression (6). Thus, the vector s is a discrete approximation of the function $j(t)$ used in the formula (6).

The search of all possible vectors s is equivalent to the combinations of numbers from 0 to n^N-1. Only one vector s corresponds to each number from the specified range. It is representation of an integer from the range from 0 to n^{N-1} if the sections are assigned numbers from 0 to n-1. In terms of combinatorics, the set of all possible values of the vector s is equivalent to the set of placements with repetitions of n different objects at N different places.

Having carried out a search and analyzing all possible values of the vector s, you can find the optimal value that determines the optimal control of the source.

The search can be shortened by using the rule: in the following stages, only those vectors s are analyzed, in which the first occurrences of the unique components increase with the increase in their serial number.

All other options for management are excluded from the subsequent analysis as identical to those options that are subject to analysis in accordance with this rule.

Let us prove the expediency of using this elimination rule for variants, that is, we show that the optimal value of the vector s coincides with its optimal value found among the set of vectors s, in which the first values of the unique components increase with the increase in their ordinal number.

Indeed, the vectors s, equivalent up to the values of its components, are equivalent in the framework of the problem being solved. For example, the vector s = (1 1 2 3 1 2) and the vectors (2 2 1 3 2 1), (3 3 2 1 3 2), (2 2 3 1 2 3), (*a a b c a b*), (*b b a c b a*) only the designation of the applied sections and are equivalent in order of their application, i.e. are equivalent in accordance with the source control law corresponding to them and, therefore, are equivalent in terms of the result achieved.

In the framework of the problem being solved, the vector s' is equivalent to the vector s'' if, as a result of changing the designations of the source sections, one can transform the vector s'' into the vector s'. Therefore, it is expedient to define the principle of section designation, which makes it possible to isolate vectors s that are subject to further analysis, and all other vectors (equivalent up to the notation of its components) are excluded from consideration.

As such principle, we accept the following: by using the next section of the source, we assign it a number one more than the maximum number among the numbers of the previously used sections, start with 1. In this case, the values of the unique components (i.e., the component, the values of which are different from each other) for the first time occurring in the vector s increase with increasing their ordinal number in the vector s. All vectors that do not comply with this principle are excluded from further consideration as equivalent to one of the vectors to be analyzed. For example, the vector (1 1 2 3 1 2) corresponds to this principle, and the vectors (3 3 2 1 3 2), (2 2 1 3 2 1), (3 3 2 1 3 2), (2 2 3 1 2 3) does not correspond and can be excluded from further consideration. It follows from the foregoing that the value of the optimal vector among all possible values coincides with its optimal value found among the set of vectors s in which the first occurrences of the unique components increase with the increase in their ordinal number.

3. For each j-th section of MCPS, the time function $I_j(t)$, $t\in[0,T]$, is produced, which determines the current requested from the j-th section by the formula:

$\forall k\in\{1,...,N\}$: if $s_k=j$, then $\forall t\in[t_k, t_k+\Delta t]$: $I_j(t) = i^*(t)$, otherwise $I_j(t) = 0$;

and the time function U^*_j, $t\in[0,T]$, determining the voltage requested from the j-th section by the formula:

$\forall k\in\{1,...,N\}$: if $s_k=j$, then $\forall t\in[t_k, t_k+\Delta t]$: $U^*_j(t) = u^*(t)$, otherwise $U^*_j(t) = 0$.

4. The problem of minimizing the capacitance C_j, $j\in\{1,..., n\}$ is solved. To this goal, from equation (6) we find:

$$C_j = Q_j(0)/(U_j(0)\text{-}U_j(T)), \tag{8}$$

where $Q_j(t) = \int I_j(\tau)d\tau$, $\tau\in[t, T]$ is the electric charge picked up from the j-th MCPS section on the time interval $[t, T]$.

It follows from formula (8) that one of the necessary conditions for minimizing the value of C_j is the equality of the initial voltage in each MCPS section to the maximum voltage:

$$U_j(0)= U^{max}, j\in\{1,..., n\}. \tag{9}$$

From equalities (8), (9) it follows that the desired optimal capacitance value of the MCPS section is:

$$C_j^{\min} = Q_j(0)/(U^{\max} - U_j(T)), j\in\{1,..., n\}. \tag{10}$$

In the resulting formula, the value $U_j(T)$ is to be chosen. The optimal value of $U_j(T)$, as follows from equation (10), should be as small as possible in order to minimize the corresponding capacitance of MCPS, and simultaneously, it must be large enough that the following conditions are fulfilled:

$$U_j(t) \geq U^*_j(t), j\in \{1,..., n\}, \forall t\in [0,T].$$

We obtain the calculated relations ensuring the optimal choice of $U_j(T)$. From equation (6) with account of (10) we find:

$$U_j(t)=U_j(T)+(U^{max}-U_j(T))Q_j(t)/Q_j(0),\ t\in [0, T]. \quad (11)$$

The conditions $U_j(t)\geq U^*_j(t), j\in \{1,..., n\}, \forall t\in [0,T]$ after substituting expressions (11) in them take the form: $U_j(T)+(U^{max}-U_j(T))Q_j(t)/Q_j(0) \geq U^*_j(t),\ _{j\in \{1,..., n\}}, \forall t\in [0,T]$, or, equivalently,
$[1-Q_j(t)/Q_j(0)]U_j(T) \geq U^*_j(t)-U^{max}Q_j(t)/Q_j(0), j\in \{1,..., n\}, \forall t\in [0,T]$.

The obtained expression for the initial time moment (at this moment $Q_j(t)/Q_j(0)=1$) leads to the obvious requirement: $U^*_j(0) \leq U^{max}$. For the remaining instants of time $t\geq 0+\varepsilon$, $\varepsilon>0$, we obtain:
$U_j(T)\geq[U^*_j(t)-U^{max}Q_j(t)/Q_j(0)]/[1-Q_j(t)/Q_j(0)]$, $j\in \{1,..., n\}, \forall t\in [0+\varepsilon, T]$.

Starting from minimizing the value of $U_j(T)$, we find

$$U_j(T)=\max\,[U^*_j(t)-U^{max}Q_j(t)/Q_j(0)]/[1-Q_j(t)/Q_j(0)],\ t\in [0+\varepsilon,T],\ j\in \{1,..., n\}. \quad (12)$$

Having determined the optimal value of $U_j(T)$ by formula (12), we calculate the optimal values of the capacitances of MCPS sections according to equation (10).

5. The total minimum capacitance of the MCPS sections $\sum_{j=1,n} C_j$, corresponding to the analyzed variant of the vector s, is computed and stored.

6. After the search of all possible vectors s generated at the second stage of this algorithm is completed, the option s^{opt} is chosen among them, which corresponds to the minimum capacitance of the MCPS sections calculated at the fifth stage of this algorithm.

As a result of the implementation of the listed stages of the method, we find: a discrete approximation of the desired control law determined by the optimal value of the vector s found, the capacitance values of the $C_j^{\min}$ sections and the initial values of the potentials $U_j(0)=U^{max}$ in them, which ensure the minimization of the required capacitance of the MCPS.

7. For the found program for connecting MCPS sections, defined by the vector s^{opt}, following the known methods of control theory [11, 12], we determine the coefficient κ, ensuring a fairly accurate realization of the prescribed motion $\alpha^*(t)$.

The value of the coefficient κ does not significantly affect the minimum allowable total capacitance of the MCPS sections. This is because the optimal capacitance of the sections depends mainly on the trajectory of the motion α(t). It determines the profile of the functions $u^*(t)$, $i^*(t)$, which in turn determine the optimal connection law and the capacitance of the MCPS sections.

If the coefficient κ is chosen so that the accuracy of realization of the prescribed motion is high, this means that in this case the function $\alpha(t)$ is close to the function $\alpha^*(t)$ and the subsequent actions described in the above method lead to the result that is invariant to the value of the coefficient κ.

This circumstance makes it possible to realize the separation of the synthesis of the control law realized in the proposed method into two problems: the problem of choosing the optimal dependence $j(t)$ in formula (7), which determines the sequence of use of the MCPS sections, and the problem of choosing the optimal value of the coefficient κ in formula (6).

The accuracy of the solution obtained can be estimated on the basis of modeling a synthesized control system using equations (1-7).

If the control law found ensures the achievement of a specified accuracy of the implementation of the specified motion, then the process of solving the required task is successfully completed.

Otherwise, it is possible to improve the accuracy of the implementation of the specified motion through an increase of the amplitude of the control action determined according to expression (7), i.e., on the basis of an increase of U_j. To achieve this, the values of C_j are increased to the levels ensuring the required accuracy.

The above method assumes that the number of source sections is specified. However, it can be extended to a more general case where the number of sections is to be determined. In such a case, it seems rational to consistently increase the number of sections of the source from one to a value, when a further increase in their number does not lead to a sufficiently significant decrease in the required capacitance of the source. Thus, a reasonable compromise is achieved between the complication of the source design and the decrease in its capacitance.

4 Example of the control law synthesis

Consider the implementation of the proposed method in relation to the task described above, in which the program of motion of the output link of the drive is given in the form of a polynomial: $\alpha^*(t)=(\gamma_0 t+\gamma_1 t^2/2+\gamma_2 t^3/3+\gamma_3 t^4/4)/k_g,\ t\in [0, T]$.

Therefore, given equality (4), the program for changing the coordinate of the motor shaft is described by a polynomial: $\varphi^*(t)=\gamma_0 t+\gamma_1 t^2/2+\gamma_2 t^3/3+\gamma_3 t^4/4$, and the speed change program is given by the polynomial: $\omega^*(t)=\gamma_0+\gamma_1 t+\gamma_2 t^2+\gamma_3 t^3$.

Let us consider an application in which the drive opens a safety valve. At the initial time t=0, the valve is closed.

When the valve has "closed" status, all variables of the system under consideration have zero values. During the opening process, the valve is moved by the drive from the "closed" state to the "open" state in a given time T.

At time $t=T$, the coordinates α^*, φ^* take values corresponding to the state of the valve "closed": $\alpha^*(T)=\alpha_T$, $\varphi^*(T)= \alpha_T k_g$.

When switching to the valve state "closed", it is necessary that the valve plug comes into contact with the seat smoothly.

Mathematically, this requirement is described by the conditions $\omega(T)=0$, $\alpha^*(T)=\alpha_T$, $\alpha(t)\leq\alpha_T$, $t\in[0, T]$.

Since at the initial and final moment of time the program value of the speed $\omega^*=0$, we get: $\gamma_0=0$, $\gamma_1+\gamma_2T+\gamma_3T^2=0$, or $\gamma_0=0$, $\gamma_1= - (\gamma_2T+\gamma_3T^2)$.

We take into account that $\varphi^*(T)= \alpha_Tk_g$.

Then: $\alpha_Tk_g=\gamma_0T+\gamma_1T^2/2+\gamma_2T^3/3+\gamma_3T^4/4$.

Using the values of γ_0, γ_1, found above, we obtain: $\alpha_Tk_g=-(\gamma_2T+\gamma_3T^2)T^2/2+\gamma_2T^3/3+\gamma_3T^4/4$, from which the following value is found: $\gamma_2 =-6(\alpha_Tk_g/T^3+\gamma_3T/4)$.

Let us select the following parameters of the system: $\alpha_Tk_g=12\pi$, $k_g= 1200\pi$ *rad/m*, i.e. the motor shaft makes 6 full revolutions resulting in the stroke of the plug of $\alpha_T=10^{-2}$ *m*.

Let us select T=1 s,γ_3=-450, then: $\gamma_0=0$, $\gamma_1=1.20$ *rad/s*^{2}, $\gamma_2=448.81$ *rad/s*^{3}.

We assume that the law of the change in the load torque $M(t)$ is given by the polynomial $M(t)=\mu_0+\mu_1t+\mu_2t^2+\mu_3t^3$ in which: $\mu_0=15$ *Nm*; $\mu_1=0.1$ *Nm/s*; $\mu_2=0.07$ *Nm/s*^{2}; $\mu_3=-0.1$ *Nm/s*^{3}.

The graphs of the functions $\alpha^*(t)$, $\omega^*(t)$, $M(t)$, $t\in[0,T]$ are shown in Figure 1.

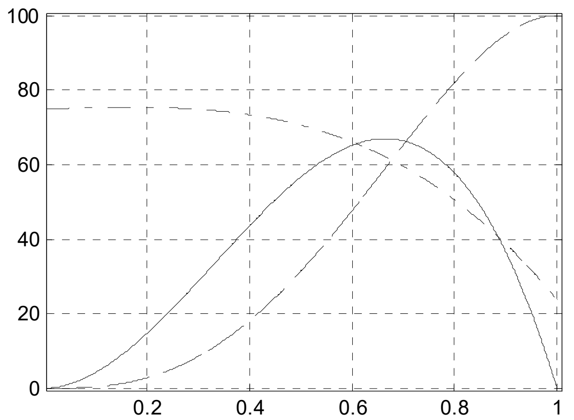

Fig. 1. The graphs of the functions $\alpha^*(t)\cdot10^4$, $\omega^*(t)$, $M(t)\cdot5$ (respectively - dashed, solid, dot-dash line).

The motor parameters have the following values: C_e=1.50 *V·s/rad*; C_m=1.32 *Nm/A*; $L=15\cdot10^{-4}$ *H*; R=1 Ω; $J=10^{-2}$ *kg·m*^{2}; U^m=150 *V*.

Further we proceed with the computations according to the method proposed above.

Solving the inverse problem of dynamics [9, 10] for the above-mentioned values of the drive parameters and the functions $\alpha^*(t)$, $M(t)$, with respect to the equations (1)-(4), we find the functions $u^*(t)$, $i^*(t)$, $t\in[0,T]$: their graphs are shown in Figure 2.

In the case of an MCPS consisting of one section (n=1), we determine by formula (12) the optimum value of the voltage at the output of the MCPS at the final instant of time $U_1(T)$=100,86 *V*.

Then, according to equation (10), we find the optimum capacitance of a single-section MCPS: C_{min} = 195.8 *mF*. The processes that characterize the functioning of the drive when the valve is open in the case of an MCPS consisting of a single section are shown in Figure 3. The coefficient κ in the control law (7) is chosen to be 50.

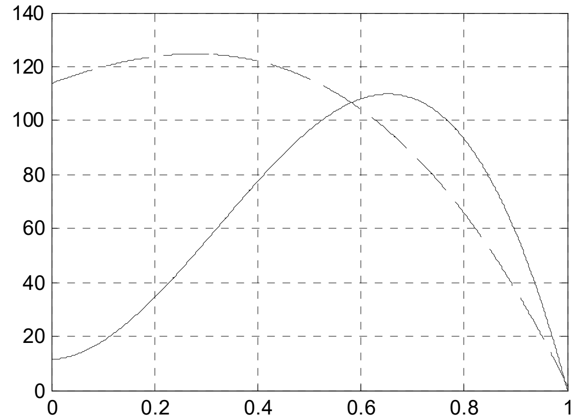

Fig. 2. The graphs of the functions $u^*(t)$, $i^*(t)$ 10, (respectively - solid, dashed line).

The optimal choice of the MCPS capacitance is characterized by the point of contact of the graphs of the functions $u^*(t)$ and $u(t)$ observed in Figure 3.

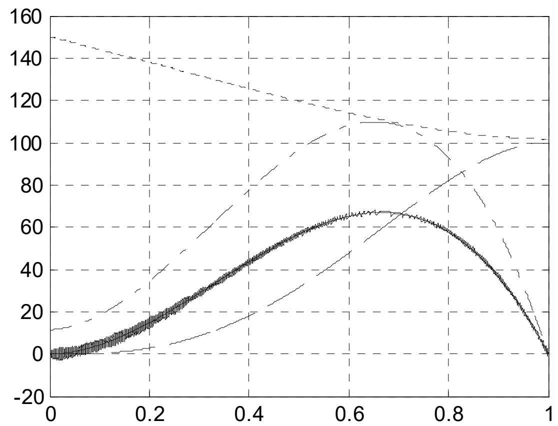

Fig. 3. The graphs of the functions $\alpha^*(t)$ 10^4, $\alpha(t)$ 10^4, $\omega^*(t)$, $\omega(t)$, $u^*(t)$, $u(t)$ in MCPS with the number of sections n=1 (dashed, dashed, solid, solid, dot-dash and dotted lines).

Assign the number of MCPS sections to n=3.

The interval of time [0,1] is divided into N = 10 equal parts. We generate and analyze vectors s, taking into account the above recommendations.

As a result of the search of vectors s, we find the optimal value s_{min}=(0 0 1 1 2 2 2 2 2 2 1). The coefficient κ in the control law (7), as in the case of a single-compartment MCPS, was chosen to be 50.

Figure 4 shows the processes corresponding to the solution found, characterizing the operation of the actuator when the valve is open in the case of an MCPS consisting of three sections.

Analyzing the obtained s_{min} value and the graph of $u(t)$, we see that the charge of the 0-th section is first consumed, then the 1st, 2nd, and the charge of the 1st section is again consumed at the final time step.

The optimum capacitance values of the MCPS sections are: C_0^{min}=20.55 *mF*; C_1^{min}=34.04 *mF*; C_2^{min}=79.06 *mF*. Residual voltages in MCPS sections: $U_1(T)$=33.66 *V*, $U_2(T)$=71.23 *V*; $U_3(T)$=92.46 *V*. The total capacitance is $C_0^{min}+C_1^{min}+C_2^{min}$=133.7 *mF*.

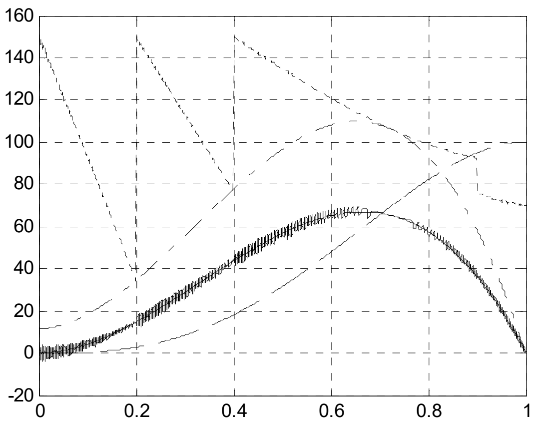

Fig. 4. The graphs of the functions $\alpha^*(t)\ 10^4$, $\alpha(t)\ 10^4$, $\omega^*(t)$, $\omega(t)$, $u^*(t)$, $u(t)$ in MCPS with the number of sections n = 3 (dashed, dashed, solid, solid, dot-dash and dotted lines).

In the example considered, the capacitance of the three-section MCPS is 1.46 times smaller than in the single-section MCPS.

5 Conclusions

A method for synthesizing the optimal for energy efficiency control law for a multi-sectional capacitor power supply of an electric drive is proposed. As a criterion of energy efficiency, the total required capacitance of MCPS sections is considered. The synthesized control law for electric drive realizing the prescribed motion, ensures the minimization of the required capacitance of the power source on the basis of rational disconnection and connection to the power line of the drive at designated times of one of the power supply sections.

Reduction of the required capacitance of the source is achieved as a result of a more complete emptying of some of its sections at time intervals with a low level of requested potential and saving high potential for upcoming time intervals in only some part of the source sections.

The task is formalized. The proposed method for solving it is based on specifying a finite set of time instants, into which the values of the control function can change. Thus, an approximation is made for the desired control law for a function that changes values at certain times from a given finite set. In this case, the specified time sampling does not extend to the other variables.

As a result, the problem reduces to analyzing a finite set of control options. A significant part of the management options is excluded from the subsequent analysis based on the application of simple logical rules, set out below. For the next analysis version of the control for the simple analytical dependencies found, the optimum values of the capacitance of the sections and the total storage capacitance of the source are calculated. Simple in the computational plan, dependencies and logical rules allow you to quickly analyze a large number of possible control options.

Among all possible variants of controls, an optimal variant is identified, to which the minimum required capacitance of the source corresponds.

An example of the implementation of the proposed method is considered for the electric drive of a safety valve. This example demonstrates the possibility of a significant reduction in the required MCPS capacitance when using the control law synthesized by the proposed method.

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