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Investigation of Transients in Secondary Sources of Traction Electric Drive on Models Using Matlab/Simulink

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ABSTRACT: This paper deals with the modelling of transients in secondary power supplies of traction electric drive using Matlab/Simulink environment. The complex analysis of dynamic characteristics of supercapacitor and accumulator systems at different modes of electric drive operation is carried out. Special attention is paid to the influence of abrupt load changes and energy recovery mode on the voltage and current stability of the sources. The results of modelling allow to identify critical modes, to determine stability reserves and to justify optimal parameters of energy sources taking into account requirements to speed and reliability of traction system. The obtained data can be used in the design of highly efficient power supply subsystems in electric transport.

KEYWORDS: traction electric drive, Matlab/Simulink, transients, secondary power supplies, supercapacitors, accumulators, energy recovery, modelling, stability**.**

I.RELATED WORK

Research on the dynamic behavior and optimization of secondary power sources in traction electric drives has gained significant attention in recent years. Various studies have focused on the modeling, design, and control of electric drives to improve their energy efficiency and operational reliability.
J. Faiz and M.B.B. Sharifian [1] explored the optimal design of three-phase induction motors, providing insights into how efficient motor design can influence the performance of electric drive systems. Zoran Stević and Mirjana Rajčić-Vujasinović [2] emphasized the application of supercapacitors as an alternative or supplementary power source for electric vehicles, highlighting their advantages in transient conditions.
Several investigations have addressed the analysis of energy efficiency in electric drives. Hakimov S.H. [3] presented methods for assessing the efficiency of asynchronous motors based on the energy received from their sources, contributing to a better understanding of power consumption in dynamic modes. Similarly, P.S. Machulin [4] discussed modern challenges in electric drive development, particularly concerning dynamic loads and transient phenomena.
Control strategies for electric drives have also been a major research topic. O.V. Nos [5] proposed optimal vector control techniques for asynchronous motors, minimizing stator current under varying load conditions, which is directly related to ensuring the stability of secondary sources during transient events.
Recent work by Kayumov S.N. and Khakimov S.H. [6,7] focused on developing energy-saving technologies for asynchronous motors and electrical apparatuses, emphasizing the importance of material and design innovations to enhance the energy recovery capabilities of traction drives.
Furthermore, studies on the physical and thermal properties of materials used in energy systems, such as those by Sauchuk H.K. et al. [8], and performance criteria for automated traction electric drives, as proposed by Kolesnikov I.K. et al. [9], provide valuable background for improving the stability and efficiency of secondary power supplies during transient processes.
Despite the extensive work done, there remains a need for comprehensive modeling and analysis specifically focused on the behavior of supercapacitor and accumulator systems under abrupt load changes and energy recovery modes. This

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paper addresses this gap by presenting a detailed investigation using Matlab/Simulink models to optimize the stability and dynamic performance of secondary sources in traction electric drives.

II.INTRODUCTION

Let's consider the model of single-circuit traction electric drive of the secondary power supply for electromagnetic processes, shown in (figure 1).

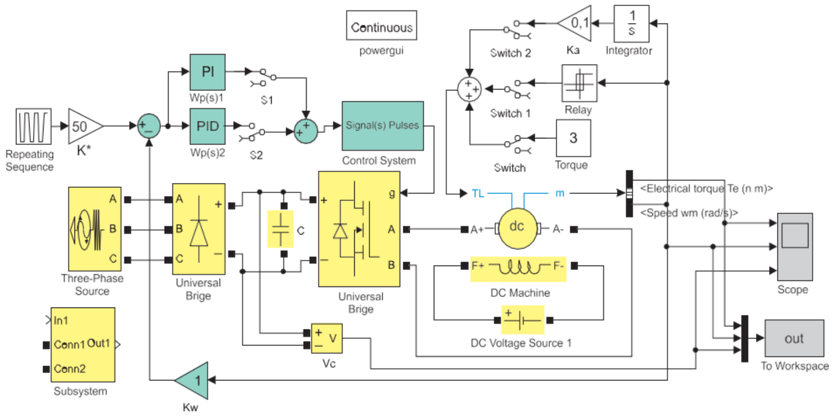

Figure 1: Model of a single-circuit traction motor

This model is designed to investigate the voltage across the secondary power supply capacitor. In the Repeating Sequence and Gain blocks the input signal is formed. In the first block the waveform and frequency are formed, in the second block the amplitude of the input signal is formed. The introduction of two blocks allows us to independently set the speed and acceleration at the input of the circuit. Blocks PI and PID represent integral and integral-differential converters. Switch1 and Switch2 represent switches that set either the PI - regulator or the PID, which simulate the perturbing influences. The DC Machine setting allows the parameter Bm (viscous friction torque) to be set. Parameters of the model blocks are shown in table 1.

Table 1: Parameters of the model blocks

Библиотека	Блок	Параметры блока
SimPowerSystems\Electrical Sources	Three-Phase Source — трехфазный источник напряжения	Phase to phase rms voltage (V) — 110/1.41, Phase angle of phase A(degrees) — 0, Frequency (Hz) — 50, Internal connection — Yg, Source resistance (Ohm) — 0.01, Source inductance (H) — 0
SimPowerSystems\Power Electronics	Universal Bridge1 — универсальный мост	Number of bridge arms — 3; Snubber resistance Rs(Ohm) — 1e5, Snubber capacitance Cs-inf, Power Electronic devices — Diodes, Ron(Ohm) — 1e-3, Lon (H) — 0, Measurements — None
SimPowerSystems\Power Electronics	Universal Bridge 2 — универсальный мост	Number of bridge arms — 2; Snubber resistance Rs(Ohm)—1e5, Snubber capacitance Cs-inf, Power Electronic devices — MOSFET/Diodes, Ron(Ohm) — 1e-2, Measurements — None
SimPowerSystems\Machines	DC Machine — машина постоянного тока	Present model-No, Mechanical input — Torque TL, Armature resistance and inductance (Ra(Ohms), La(H) — 0.585, 0.025, Field resistance and inductance (Ra(Ohms),La(H) — 400, 0, Field-armature mutual inductance Laf(H) — 1.236, Total

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		inertia J(kg.m^2) — 0.36, Viscous friction coefficient Bm(N.m.s) — 0, (устанавливается не 0 при моделировании момента вязкого трения)
SimPowerSystems\Electrical Sources	DC Voltage Source — источник постоянного тока	Amplitude (V) — 110
SimPowerSystems\Elements	C (Parallel RLC branch) — параллельная RLC-цепь	Branch type — C, Capacitance C(F) — 1000e-6, Capacitor initial voltage (V) — 110, Measurements — None
SimPowerSystems\Measurement	Vc (Voltage Measurement) — измеритель напряжения	
Simulink\Sinks	Scope — осциллограф	Урок 2
Simulink\Sinks	To Workspace — блок записи процессов в рабочее пространство	Variable name — out, Limit data points to last — 15000, Decimation — 1, Sample time — 1e-3, Save format — Array
Powerlib-Extras/Control Blocks	Control system — генератор сигналов ШИМ	Generator Mode — 2-am bridge (4 pulses), Currier frequency (Hz) — 500
Simulink\Extras	Wp(s)1, Wp(s)2 — PI, PID controller (with Approximate derivative)	(PI)-Proportional — 0.06, Integral — 0.0337, Derivative — 0, Derivative devisor(N) — 0; (PID)-Proportional — 0.6142, Integral — 0.3374, Derivative — 0.0247, Derivative devisor(N) — 1/0.0046
Simulink\Math Operation	Kw (Gain) — коэффициент обратной связи по скорости	Gain — 1
Simulink\Source	Repeating Sequence — блок сигнала на входе	
Simulink\Math Operation	K* (Gain) коэффициент	Gain — заданная скорость (рад/с)
Simulink\Source	Torque – Constant — блок постоянного момента	Constant value — значение момента
Simulink\Discontinuites	Relay — блок момента сухого трения	Switch on point — 0.01, Switch off point — 0.01 Output when on — положительное значение момента, Output when off — отрицательное значение момента
Simulink\Math Operation	Ka – Gain — коэффициент шарнирного момента	Gain — 0.1

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III. SIMULATION&RESULTS

Simulation time is t= 20 c, with Max step size (1e - 3c), which can be set Simulation parameters of the model. The program is presented in the form of (figure 2). The results of modelling with PI - regulator are shown in (figure 3), and with PID - regulator in (figure 4), where the results of modelling in the secondary power supply of electromagnetic processes in the single-circuit system of traction electric drive are given.

Листинг 1

```
t=1e-3:1e-3:15;
M=out (:,1);
n=out (:,2);
Vc1=out (:,3);
subplot (2,1,1);
plot (t, M, t, n);
grid on;
Title ('Момент и скорость в системе');
xlabel ('Время (С)');
ylabel ('Момент (Нм) Скорость (рад/с)');
text (3.2,50,'Скорость');
text (5.5,30,'Момент');
subplot (2,1,2);
plot (t,0, t, Vc1)
grid on;
Title ('Напряжение на конденсаторе фильтра');
ylabel ('Uc1(B)');
xlabel ('Время (С)');
```

Figure 2: Programme for the study of electromagnetic processes in secondary power supplies

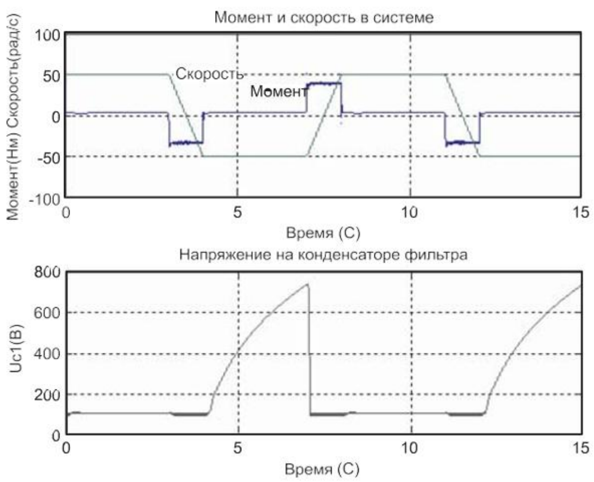

Figure 3: Modelling results of secondary power supplies in a single-circuit traction drive system with PI controller

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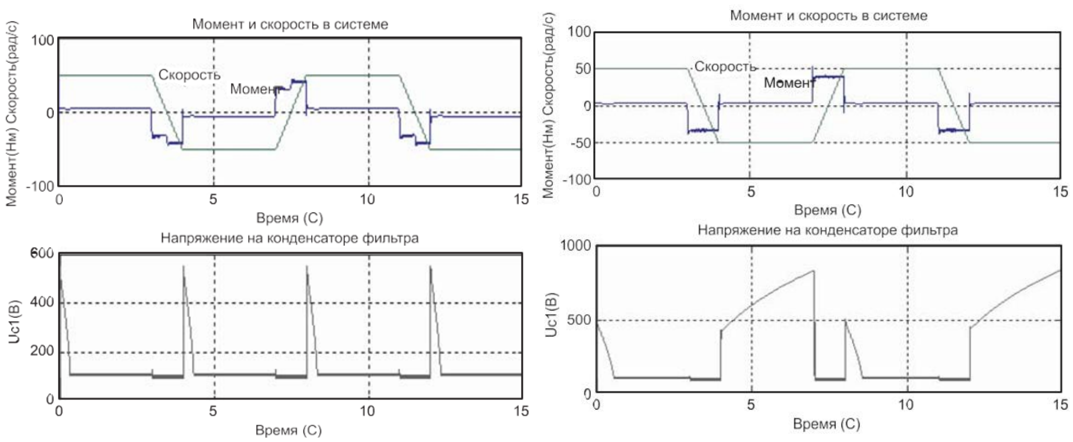

Figure 4: Results of modelling of secondary power supplies in a single-circuit system of traction electric drive with PID-regulator

(Figure 3) shows the results of modelling of secondary power supplies of a single-circuit traction drive system with PI-regulator at $M_H = 3H_M$. At positive $M_H > 0$ there is an overvoltage ΔU_C by 1,5%.

In (figure 4) with PID-regulator, the results of modelling take into account only transients, and the results of over voltages completely coincide with those calculated by equation 1.

$$\Delta U_C = \left(\frac{J\varepsilon^*}{K_\omega K_M}\right)\sqrt{\frac{L_a}{C}\left(1-\frac{t_2}{4T_a}\right)} \qquad (1)$$

The constant torque on the shaft was equal to $3H_M$. The overvoltage on the filter capacitor includes both transient and steady state. This voltage is calculated from equation 2.

$$\Delta U_C = \sqrt{\frac{L_a}{C}}\sqrt{\frac{M_H\omega^*\cdot 2t_1}{K_\omega R_a T_a}-\left(\frac{M_H}{K_M}\right)^2\left(1+\frac{2t_1}{4T_a}\right)+\left(\frac{J\varepsilon^*}{K_\omega K_M}\right)^2\left(1-\frac{t_2}{4T_a}\right)} \qquad (2)$$

It also coincides with the simulation result. To eliminate the overvoltage, an energy dump circuit has been designed, which is represented by the Subsystem block in the model and the parameters are shown in table 2. The model of the reset circuit is shown in (figure 5).

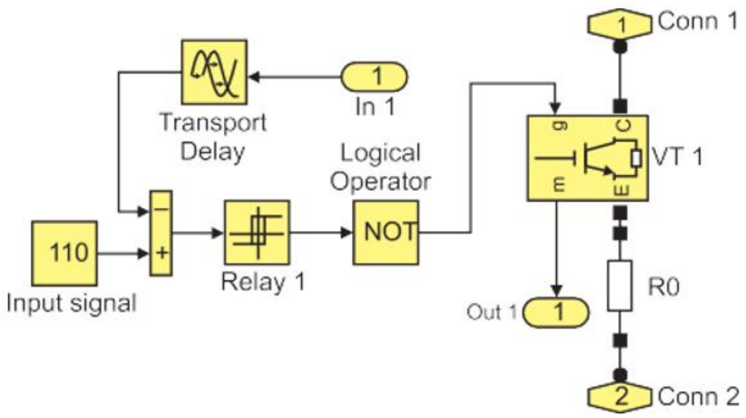

Figure 5: Energy Discharge Model

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Table 2: Parameters of the energy discharge circuit

Библиотека	Блок	Параметры
Simulink\Discontinuites	Relay1 — блок релейного регулятора	Switch on point — 0.01, Switch off point — –0.01; Output when on — 1, Output when off — 0
Simulink\Continuos	Transport Delay — блок задержки	Time Delay — 1e-6, Initial output — 0, Initial buffer size — 1024
SimPowerSystems\Power Electronics	VT1(IGBT/Diode) — IGBT-транзистор с параллельным диодом	Resistance Ron(Ohm) — 0.001, Inductance Lon (H) — 0, Forward voltage Vf(V) — 1, Current 10% fall time Tf(s) — 1e-6, Current tail time Tt(s) — 2e-6, Initial current Ic(A) - 0, Snubber resistance Rs(Ohm) —- 1e5, Snubber capacitance Cs(F) — inf
SimPowerSystems\Power Electronics	R0 (Series RLC branch) — сопротивление цепи сброса энергии	Branch type - R, Resistance (Ohm) - 1

The energy dump circuit is switched on by the Conn1, Conn2, In1 ports to the output of the V_C. Out1 output was used to measure the transistor current. The constant torque on the shaft is equal to $3H_M$.The result of modelling of electromagnetic processes in the secondary power supply with PID-regulator and with the energy dump circuit are the characteristics shown in (figure 6).

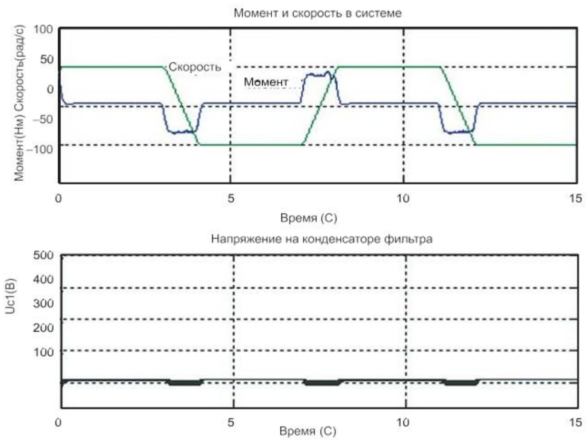

Figure 6: Results of modelling of electromagnetic processes in a secondary energy source for the purpose of energy discharge

The paper also considers the issues of dynamic processes in the two-circuit system of DC electric drive of the secondary power supply (figure 7).

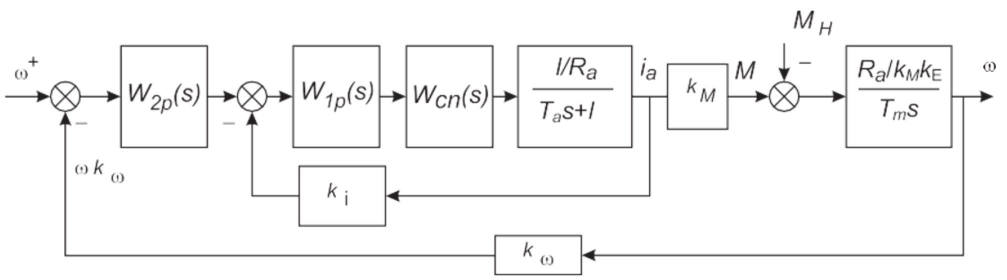

Figure 7: Structure diagram of the double-circuit electric drive

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In synthesis, the pulse-width converter can be represented as an aperiodic link with an open loop transfer function:

$$W_{\text{раз}}(S) = \frac{W_{1p}(S)K_{en}K_i/R_a}{(T_a S+1)} \quad (3)$$

When a traction motor with integral PI controller with parameters will be used in the secondary power supply, the transfer function will be:

$$W_{1\text{p}}(S) = \frac{K_{1\text{p}}(T_a S+1)}{T_a S}, \quad (4)$$

$$\text{then: } W_{\text{раз}}(S) = \frac{K_{1p}K_{\text{сп}}K_i/R_a}{(T_a S+1)} \quad (5)$$

A closed loop can be represented as:

$$W_{1\delta}(S) = \frac{1/K_i}{a_1 T_a S+1} = \frac{1/K_1}{T_o S+1}, \text{ where } a_1 = \frac{R_a}{K_{1p}K_{\text{сп}}K_i} \quad (6)$$

If PI is used - a regulator with an amplification coefficient:

$$K_{2\text{p}} = \frac{T_M K_i K_E}{a T_o K_\omega R_a} \quad (7)$$

Then the transfer function is written as:

$$\text{a} = \frac{T_M K_i K_E}{T_o K_{2\text{p}} K_\omega R_a} \quad (8)$$

If there is a negative feedback on the current, the opposite E.D.S. in the armature is compensated, and the electric motor operates in torque mode. The behavior of the working point is shown in (figure 8).

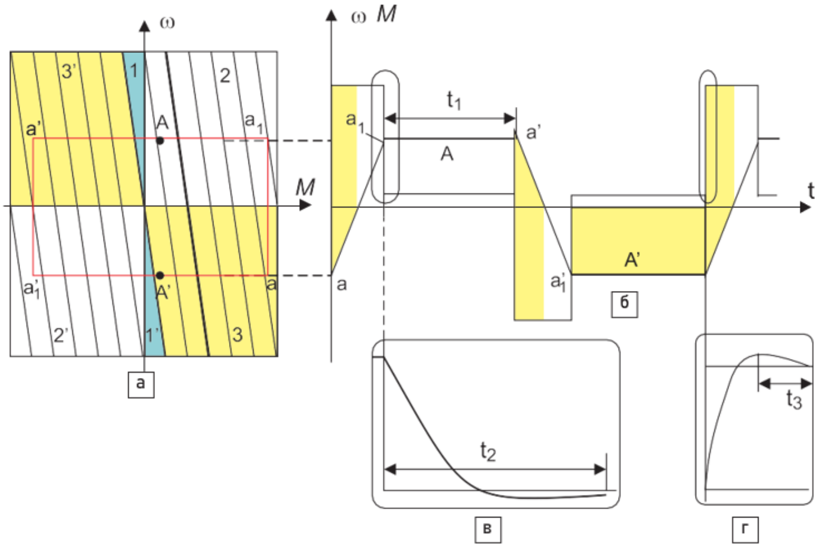

Figure 8: Electromagnetic and electromechanical processes in a closed two-circuit electric drive.

In (figure.8), the generator mode of the motor 1, 1´, but in this case it is excluded and operates only in the motor mode 2, 2´, or in the electromagnetic brake mode 3, 3´ (figure 8a).
Therefore, when $M_H = const$, mechanical energy is dissipated in the resistance.
Overvoltage on the filter capacitor occurs only in transient mode. If the torque jumps down (figure.8c), the same processes as in the single-loop system occur. At a≤2, overshoot occurs. In this case, all the energy stored in the armature inductance is transferred to the capacitor.
The overvoltage on the capacitor, which is caused by overshoot when the torque jump changes is very small.
The model for the study of electromagnetic and electromechanical processes in the secondary power supply of a double-circuit traction drive is shown in (figure. 9).

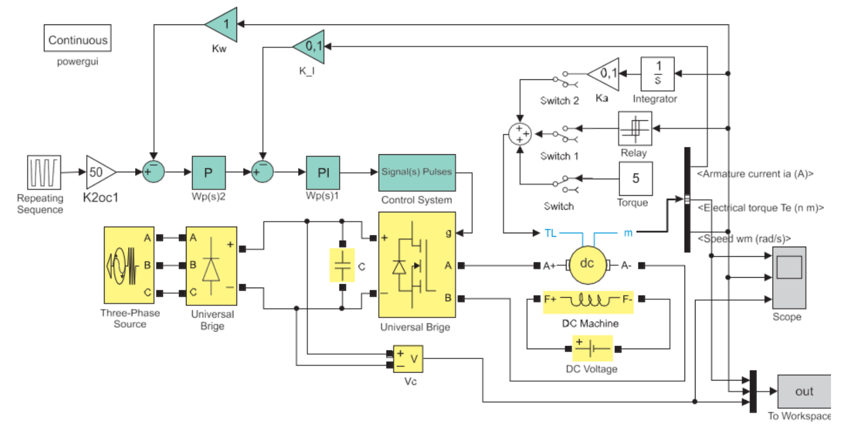

Figure 9: Model of a double-circuit secondary power supply drive

The model parameters do not change with respect to the single-loop system and are presented in Table3.
Table 3: Parameters of the energy discharge circuit

Параметры регуляторов	kП	kИ
ПИ-регулятор тока	0,5682	13,2955
П-регулятор скорости	13,2392	

The parameters of the regulators in table 3 are presented to adjust the system to the optimum values. The results of modelling of the two-loop system with PI - regulator and P - speed regulator at $M_H = 3H_M$ are presented in (figure 10). Overvoltages occur only in transient mode, and in (figure 11) they occur due to transient process and at overshoot.

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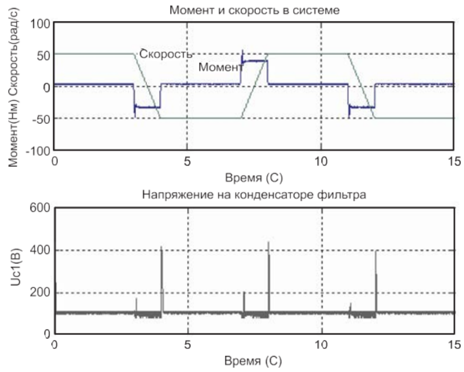

Figure 10: Results of modelling of electromagnetic processes in the secondary power supply

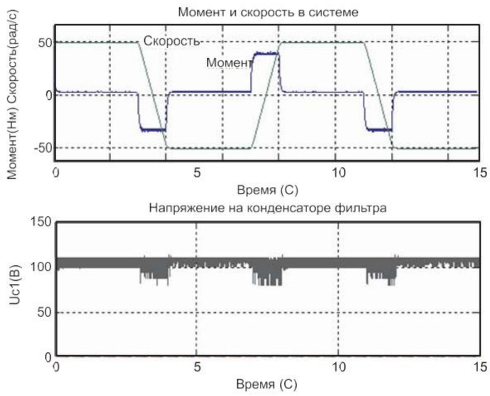

Figure 11:

To reduce the overvoltage, it is necessary to increase the capacitance of the capacitor or choose a regulator that satisfies the condition $t_2 \geq 4T_a$. This regulator has a coefficient $K_{2p} = 2{,}5$.

IV. CONCLUSION

This study has presented a detailed investigation of transient processes occurring in the secondary sources of traction electric drives through dynamic modeling and simulation in MATLAB/Simulink. By developing comprehensive models that accurately replicate the electrical and electromechanical behavior of secondary energy sources under various operating conditions, critical insights into their transient characteristics were obtained.

The simulation results have demonstrated that transients significantly impact the stability, efficiency, and reliability of traction systems, particularly during rapid load changes, regenerative braking, and fault conditions. Key parameters influencing transient responses, such as capacitance, inductance, and control strategies, were identified and analyzed.

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Furthermore, the effectiveness of different mitigation techniques, including optimized control algorithms and improved energy storage configurations, was evaluated.

Overall, the findings emphasize the importance of careful design and management of secondary energy sources to enhance the operational performance and durability of traction electric drives. The developed models offer a valuable platform for further research, including the optimization of system parameters, the integration of renewable energy sources, and the implementation of advanced predictive control methods. Future work will extend these models to real-time simulation environments and experimental validation to bridge the gap between theoretical analysis and practical application.

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