Mathematical Modeling of the Electric Drive with Universal Power Semiconductor Converter

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Abstract. In the article are examined the mathematical models of the electric drive of direct and alternating current with the universal power semiconductor converter. The functional diagram of electrical power semiconductor converter is described. Are given the oscillograms of the output voltage of power semiconductor converter, obtained with the aid of the model of converter. Are determined the static and dynamic characteristics of the electric drive of direct and alternating current with the universal power semiconductor converter, which make it possible to positively estimate fitness for work and accuracy of the systems of electric drive in the steady-state and dynamic behaviors of work. The experimental studies, carried out in the laboratory mock-up of the electric drive of direct and alternating current with the universal power semiconductor converter, testify about the sufficiently high adequacy of the developed models and confirm the practical possibility of designing of the class of universal semiconductor converters for regulating the angular velocity of the electric motors of direct and alternating current.

1. Introduction
Power semiconductor converters (PSC) are one of most important components of the contemporary adjustable electric drive [1].

Power semiconductor converters are divided into two large groups: direct-current converters and the converters of alternating current. The first of the enumerated groups of converters is intended for regulating of direct current and voltage in the load, the second - for regulating of alternating current and voltage [2]. The basic types of direct-current converters it is possible to consider the controlled rectifier (CR) and pulse-width converter (PWC), whereas to the basic types of the converters of alternating current should be carried the regulator of voltage ( RV) and frequency converter (FC).

The practice of the use of power semiconductor converters shows that in a number of cases it is convenient to have the certain universal power semiconductor converter (UPSC), which combines in itself the possibilities of regulating both a constant, and alternating voltage in the load. The development of this UPSC will make it possible to reduce the nomenclature of necessary PSC and to reduce the necessary quantity of the technical documentation.

Entire above-mentioned explains significant interest in UPSC, research on the schemes of which is convenient to carry out with the use of mathematical simulation.
The packet is the well recommended itself means of mathematical simulation MatLab [3, 4] with the widely developed applications (Toolboxes), from which Toolbox Simulink it is well fitted out for synthesis and analysis of different electrical systems [5].

Purpose of this work - a study with the aid of the mathematical models of the static and dynamic characteristics of the schematic of electric drive with UPSC proposed.

2. Mathematical models
For developing the mathematical model of electric drive with UPSC we will use the approach, presented in [6 -10]. To figure 1, where is shown the functional diagram of electric drive with UPSC, are designated the following blocks: V1, V2 - diode rectifiers, assembled according to three-phase bridge diagram; F – ripple filter; AIV – the transistor autonomous inverter of voltage; CSI – control system of inverter; M1 – alternating-current motor (induction motor with the short circuit by rotor); M2 – direct-current motor (with the separate excitation).

The diode rectifier V1 converts the alternating voltage of power line (~Up) into rectified constant voltage (=U), which then by ripple filter F (usually inductive-capitance) it will be given in the form the voltage of supply (=Ud) on the inverter AIV. To the output AIV can be connected either the alternating-current motor M1 or through the rectifier V2 - the direct-current motor M2. Output frequency AIV (fout1) is regulated with the aid of microprocessor CSI, moreover the amplitude of output alternating voltage AIV (~Uout1) and the amplitude of the output constant voltage V2 (=Uout2) also is regulated in the block CSI with the aid of pulse-width modulation (PWC). As a rule, three-phase bridge diagram on the IGBT- transistors is used as the structure diagram of inverter.

![Figure 1. Functional diagram of electric drive with UPSC.](image)

The virtual laboratory model of the system of electric drive “universal power semiconductor converter – induction motor” (further UPSC - AM) is given to figure 2 and is intended for studying the static and dynamic characteristics of this system.

The following blocks enter into the composition of model: dc power supply (DC Voltage Source); power part UPSC (Invertor IGBT); the system of administration UPSC (Invertor Control System); induction motor with the short-circuited rotor (Asynchronous Machine); the load of induction motor with the short-circuited rotor (Mechanical Load); the set of instruments for measuring of angular velocity, moment (Scope 1) and stress on the stator of induction motor with the short-circuited rotor (Scope 2).

Regulating the value of stress on the stator and frequencies of the rotation of engine is produced by changing the parameters CSI (Invertor Control System, the parameters Frequency of output voltage and Modulation index). A change in the moment of the load of the engine M1 (Asynchronous Machine) is produced by timing and value of the jump of the load (Mechanical Load).
With the aid of the model, depicted to figure 2, was determined the oscillogram of voltage on the output of virtual model UPS (figure 3). This oscillogram illustrates the method of pulse-width modulation for obtaining necessary of form and amplitude of the output voltage of inverter used.

Also with the aid of the model, depicted to figure 2, was determined the regulation characteristic of output voltage UPSC on the idling $U_{out} = f (fout)$, where $fout$ - output frequency UPSC; $U_{out}$ - voltage on output UPSC (on the engine). The obtained characteristic $U_{out} = f (fout)$ is shown to figure 4.
In addition to this with the aid of the model of figure 2 were determined the mechanical characteristics of the system \( W_{\text{M}} = f(M) \) with the the \( f_{\text{out}} = 25 \) and \( 50 \) Hz. The data of characteristic are cited to figure 5 and are designated by index “m”. The mechanical characteristics of system UPSC-AM go they in parallel and possess significant hardness.

The experimental studies, carried out in the laboratory mock-up of electric drive with UPSC, make it possible to speak about the sufficiently high adequacy of the model of figure 2. About this testify the experimental mechanical characteristics of system UPSC-AM, also shown to figures 4 – 5 and having the index «e».

As can be seen from the comparisons of model and experimental data of figures 4 and 5, an error in the mechanical characteristics engine, obtained with the aid of the mathematical simulation, does not exceed 5 %.

Thus, the constructed on program MATLAB mathematical models of system UPSC-AM with the adequate accuracy describe static behavior.

The dynamic engine characteristics in the system UPSC-AM \( W_{\text{M}} = f(t), M_{\text{M}} = f(t) \) and \( U_{\text{M}} = f(t) \) are shown to figure 6. Data of the characteristic of the engine \( W_{\text{M}} = f(t) \) in the system UPSC-AM testify about the stability of system UPSC-AM in the starting regime and the regime of the spasmodic rise of nominal load \( (M = 1,15 \text{ nm}) \).

![Figure 5](image_url)

**Figure 5.** Mechanical characteristics of the model of system UPSC-AM: upper curves – with 50 Hz, lower curves – with 25 Hz.

Parameters of the transient process \( W_{\text{M}} = f(t) \) with an abrupt change in the controlling influence of \( f_{\text{out}} \) s 0 to 50 Hz following: the starting time of \( t_p = 0,25 \text{ s} \), the overregulation \( \sigma_m = 0 \% \), static error with the rise of load \( (M = 1,15 \text{ nm}) \) \( \delta = 9,8 \% \).

The virtual laboratory model of the system of electric drive “universal power semiconductor converter is – direct-current motor” (further UPSC-DCM) is given to figure 7 and is intended for studying the static and dynamic characteristics of this system.

The diagrams of voltages and output current of model UPSC-DCM are given in figure 8. With the aid of the model of figure 7 were determined regulation \( U_{\text{out}} = f(\text{fout}) \) and electromechanical characteristics of the system UPSC-DCM Of \( W_{\text{M}} = f(I) \) with the the \( f_{\text{out}} = 25 \) and \( 50 \) Hz. The data of characteristic are cited respectively to figures 9 - 10 and are designated by index “m”. The electromechanical characteristics of system UPSC-DCM go they in parallel and possess significant hardness.
The launch procedure of the model of direct-current motor in the system UPSC-DCM is demonstrated on the diagrams, given to figure 11. The diagrams of signals at the output of model UPSC-DCM (figure 8), static characteristics (figures 9 - 10) and the diagram of launching direct-current motor (figure 11) testify about the fitness for work of model UPSC-DCM, given to figure 7.

Parameters of the transient process $W_M = f(t)$ with an abrupt change in the controlling influence of $f_{out}$s 0 to 50 Hz following: the starting time of $t_p = 3$ s, the overregulation $\sigma_m = 0\%$.

Figure 6. Dynamic engine characteristics in the system UPSC-AM.
Figure 7. Model of the system UPS-DCM.

Figure 8. Diagrams of signals at the output of the model of system UPSC-DCM: upper is – voltage on output AIV, average - voltage on the output V2, lower – output current V2.
Figure 9. Regulation characteristic of system UPS-DCM.

Figure 10. Electromechanical system characteristic UPS-DCM.

Figure 11. Diagrams of launching the electric motor of direct current in the system UPS-DCM: the upper – angular velocity, lower is – the current of engine.
3. Conclusion
The experimental studies, carried out in the laboratory mock-up of electric drive with UPSC, make it possible to speak about the sufficiently high adequacy of the model of figure 7. About this testify experimental regulation and the electromechanical characteristics of system UPSC-DCM, shown to figures 8 – 9 and having index “e”.

As can be seen from the comparison of model and experimental data figures 8 and 9, an error in the electromechanical engine characteristics, obtained with the aid of the mathematical simulation in the regimes, close to the nominal, does not exceed 5 %. Thus, the constructed on program MATLAB mathematical models of system UPSC-DCM with the adequate accuracy describe static behavior.

In the course of studies the static and dynamic characteristics of the systems of electric drive with the universal power semiconductor converter were determined. The represented characteristics make it possible to positively estimate the fitness for work of the systems of electric drive UPSC-AM and UPSC-DCM in the steady-state and dynamic behaviors of work.

References
[1] Bose B K 2000 *IEEE Trans. Power Electron.* **15**-4 688-701
[2] Blaabjerg F, Chen Z and Kjaer S B 2004 *IEEE Trans. Power Electron.* **19**-5 1184-1194
[3] Giridharan K, Chellamuthu C, Kannabhiran A and Santhi R 2016 *East Journal of Electronics and Communications* **16**-4 859-879
[4] Tety P, Asseu O, Diby A, Konan H and Gbegbe R 2017 *East Journal of Electronics and Communications* **17**-5 1-12
[5] Zakaryukin V P, Kryukov A V 2015 *Power Technology and Engineering* **49**-4 304-309
[6] Irwanto M, Alam H, Mashor M Y, Masri M, Haziah A H, Ismail B and Butar-Butar A H 2017 *Far East Journal of Electronics and Communications* **17**-5 1167-1176
[7] Balaji R, Karthick V and Thulasi J A 2015 *Journal of Advanced Engineering* **2**-2 46-50
[8] Walker G R and Serbia P C 2004 *IEEE Trans. Power Electron.* **19**-4 1130-1139
[9] Guo X, Cavalcanti M C, Farias A M and Guerrero J M 2013 *IEEE Trans. Power Electron.* **28**-6 2635-2637
[10] Xiao H and Xie S 2012 *IEEE Trans. Power Electron.* **27**-4 1799-1808