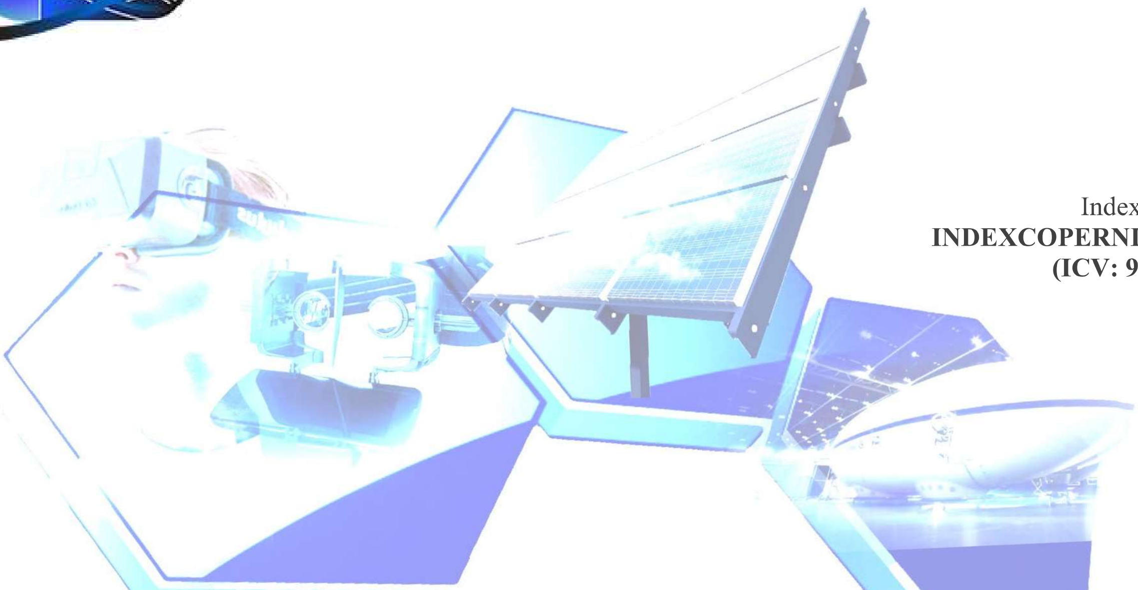
ISSUE №16
Part №1

International periodic scientific journal

ONLINE

www.moderntechno.de



Indexed in
INDEXCOPERNICUS
(ICV: 98.95)

MODERN ENGINEERING AND INNOVATIVE TECHNOLOGIES

Heutiges Ingenieurwesen und innovative Technologien

Issue №16
Part 1
April 2021

Published by:
Sergeieva&Co
Karlsruhe, Germany

ISSN 2567-5273
DOI 10.30890/2567-5273

UDC 08
LBC 94
DOI: 10.30890/2567-5273.2021-16-01

Published by:
Sergeieva&Co
Lußstr. 13
76227 Karlsruhe, Germany
e-mail: editor@moderntechno.de
site: www.moderntechno.de

Abstract. *The sensitivity of damping as applied for the diagnosis of edge transverse crack in the simply supported beam of circular cross-section at bending was investigated. As a result, a formula has been developed to assess the sensitivity of damping ability for the detection of damage.*

Key words: *damping, simply supported beam, edge transverse crack, bending vibration, damage diagnostics.*

Научный руководитель: д.т.н., проф. Бовсуновський А.П.

Статья отправлена: 28.04. 2021 г.

http://www.moderntechno.de/index.php/meit/article/view/meit16-01-035
DOI: 10.30890/2567-5273.2021-16-01-035

UDC 621.314

SIMULATION OF POWER LOSSES IN THE FREQUENCY CONVERTER

МОДЕЛИРОВАНИЕ ПОТЕРЬ МОЩНОСТИ В ПРЕОБРАЗОВАТЕЛЕ ЧАСТОТЫ

Nerubatskyi V. P. / Нерубацкий В. П.
c.t.s., as.prof. / к.т.н., доц.
ORCID: 0000-0002-4309-601X
SPIN: 5106-4483
Plakhtii O. A. / Плахтий А. А.
c.t.s. / к.т.н.
ORCID: 0000-0002-1535-8991
Hordiienko D. A. / Гордиенко Д. А.
postgraduate / аспирант
ORCID: 0000-0002-0347-5656
Karpenko N. P. / Карпенко Н. П.
c.t.s., as.prof. / к.т.н., доц.
ORCID: 0000-0002-9252-9934
Ukrainian State University of Railway Transport, Kharkiv, Feierbakh sq., 7, 61050
Украинский государственный университет железнодорожного транспорта, Харьков, пл. Фейербаха, 7, 61050

Abstract. *The article presents a method of computer simulation of static and dynamic power losses in semiconductor diodes and transistors of the semiconductor converter SIEMENS SINAMICS G110.*

Analytical expressions describing static and dynamic power losses in power semiconductor diodes and transistors are given. Mathematical expressions were obtained by the method of polynomial approximation of power characteristics of IGBT modules, on the basis of which the block of calculation of static and dynamic power losses was developed in the Matlab / Simulink program.

A computer model of the SIEMENS SINAMICS G110 frequency converter was developed using blocks from the SimPowerSystem library, on which the study of power loss components was performed.

The results were verified by comparing the simulation data with the data of the frequency converter manufacturer. With the help of the developed unit for calculating power losses, the dependences of power losses on the switching frequency and load current are obtained. The dependences of power losses on the frequency of pulse-width modulation are investigated.

Key words: *frequency converter, uncontrolled rectifier, autonomous voltage inverter, pulse-width modulation, static losses, dynamic losses, efficiency.*

Introduction. Conversion of AC mains voltage with DC amplitude and frequency into AC voltage with adjustable amplitude and frequency parameters can be performed using a frequency converter, made according to the scheme with a DC circuit [1, 2]. Such a frequency converter includes an input uncontrolled rectifier, the output of which is a smoothing filter and a autonomous voltage inverter (AVI) with pulse-width modulation (PWM) on IGBT-transistor modules [3, 4]. One of the simplest converters of this type is the SIEMENS SINAMICS G110 frequency converter, the scheme of which is presented in Fig. 1. The frequency converter is powered by an AC mains voltage of 220 V and a frequency of 50 Hz. The frequency converter includes an input uncontrolled bridge rectifier on diodes *VD7…VD10*, a smoothing filter on capacitor *C1* and a stand-alone three-phase bridge voltage inverter on six IGBT-transistors *VT1…VT6*, to which the diodes *VD6* are connected in opposite direction.

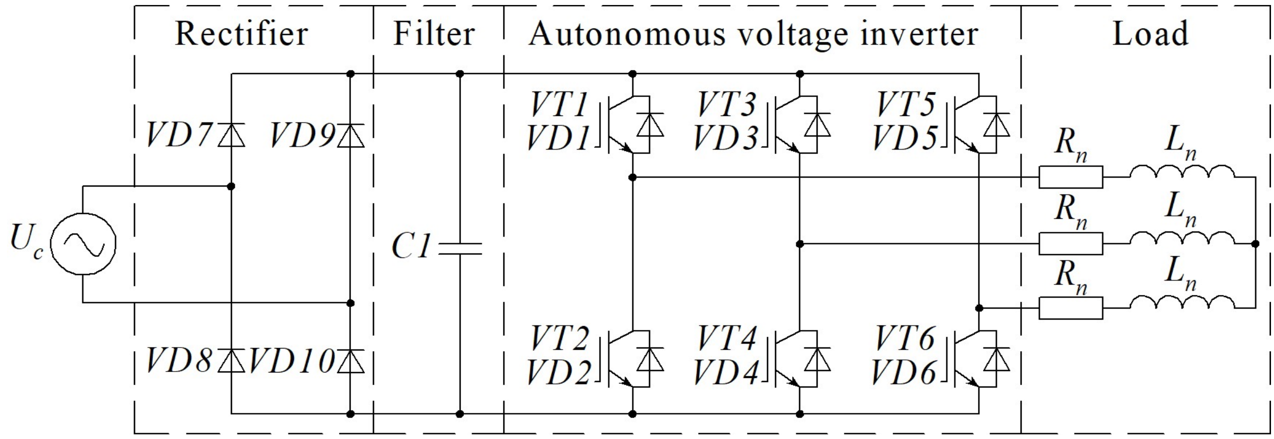


Figure 1 – Structural scheme of the frequency converter

The load of the inverter (R_n, L_n) is included in the diagonal of the AC AVI.

A significant part of the losses occurring in the frequency converter connected to the network, mainly occur in the bridge rectifier, consisting of diodes and losses in the AVI modules, consisting of IGBT-transistors and connected to them reverse diodes [5, 6]. The additional losses that occur in the capacitor on the DC side, the cooling system, the control system in this article are neglected.

In frequency converter, the losses that occur in the uncontrolled rectifier and in the AVI can be critical [7, 8]. In this paper, the losses in rectifier and inverter systems are considered. Currently, for these types of losses, there are different ways to calculate them accurately, but with a rather complex formula and complex parameters. Therefore, these calculation methods are not easy to implement in practice. Therefore, it is necessary to determine the losses in the rectifier circuit and in the AVI circuit by simulation.

The work continues the research performed by the authors in previous years and is based on the results and scientific achievements, partially published in [9–12].

Main text. The reliability and usefulness of the proposed method of modeling the calculation of power losses is assessed by comparing the results given in the documentation of the frequency converter SIEMENS SINAMICS G110, and physical modeling in the MATLAB environment.

Technical data of the SIEMENS SINAMICS G110 frequency converter are given in Table 1.

Table 1

Technical data of the SINAMICS G110 frequency converter

Parameter	Value
Network voltage, V	230
Network frequency, Hz	50
Output power, kW	1.5
Losses, W	118
Efficiency	0.927
Pulse frequency, kHz	8

The SIEMENS SINAMICS G110 frequency converter with a power of 1.5 kW in the diode uncontrolled rectifier uses the brand of the module GBPC2508W, the electrical data of which are given in Table 2.

Table 2

Basic data of the rectifier diode module GBPC2508W

Parameter	Value
Maximum pulse repeating voltage U_{RRM}, V	800
Long direct current I_o, A	25
Maximum peak direct current in one cycle I_{FSM}, A	400
Maximum voltage drop in the forward direction U_{FM}, V	1.1

In the Table 3 shows the electrical data of the module of IGBT-transistors with a reverse diode type FS15R06XE3, used in the frequency converter SIEMENS SINAMICS G110.

Table 3

Basic data of IGBT transistors and reverse diodes

Parameter	Value
Voltage collector-emitter U_{CES}, V	600
Collector current I_{cnom}, A	15
Repetitive peak collector current I_{CRM}, A	30
Collector-emitter saturation voltage U_{CEsat}, V	1.55
Energy loss when turning on E_{on}, mJ	0.25
Energy loss when switched off by the pulse E_{off}, mJ	0.34
Repetitive peak reverse voltage in the diode U_{RRM}, V	600
DC direct current of the reverse diode I_F, A	15
Direct voltage U_F, V	1.6
Reverse reduction energy of diode E_{rec}, mJ	0.16

The process of switching current and voltage in the IGBT-key and the graphical distribution of static P_{DC} and dynamic losses E_{SW} are shown in Fig. 2.

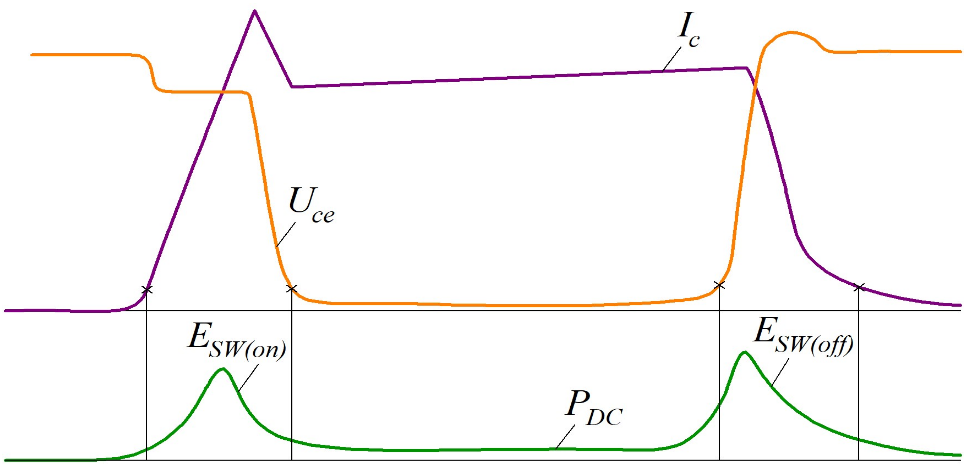


Figure 2 – Distribution of static P_{DC} and dynamic E_{SW} losses

The losses in the IGBT AVI module include conduction and switching losses in the IGBT-transistor and in the reverse diode. Conduction losses in IGBT-transistors occur when the state is on [13, 14].

Losses P_{cond} can be calculated as the product of collector current (I_c) and collector-emitter voltage (U_{ce}) [15, 16]:

$$P_{cond.inv} = \frac{1}{2\pi}\int_0^{\pi}\left(U_{ce}(I_c)\cdot I_c \cdot D_{on}\right)\cdot dt\,, \tag{1}$$

where I_c is the collector current; U_{ce} is the collector-emitter voltage; D_{on} is the time during which the IGBT-transistor is in the on state.

Dynamic losses in IGBT-transistors occur during the transition from one steady state to another, ie during the transition from off to on (dynamic on loss) and, conversely, from on to off (dynamic off loss) [17, 18]. Switching energy losses can be varied depending on the device current, voltage, gate resistance and transition temperature [19, 20].

The value of the average power of switching losses is defined as [21]:

$$P_{sw.inv} = \left[E_{on}\left(I_c\right) + E_{off}\left(I_c\right)\right]\cdot f = \int_{t1}^{t2}\left[\left(I_c \cdot U_{ce}\right)\right]\cdot dt + \int_{t3}^{t4}\left[\left(I_c \cdot U_{ce}\right)\right]dt\,, \tag{2}$$

where $E_{on}\,(I_c)$ is the power at start-up, which depends on the magnitude of the collector current; $E_{off}\,(I_c)$ is the energy at shutdown, which depends on the value of the collector current; f is the switching frequency.

Total losses in the frequency converter can be determined by the following expression [22, 23]:

$$P_{FC} = P_{con.rec.} + P_{con.inv.} + P_{SW.inv.}\,. \tag{3}$$

Switching losses that occur in the frequency converter make a significant contribution to the total losses in the AVI [24, 25]. In order to accurately estimate the efficiency of the frequency converter and increase the reliability of the design, it is necessary to accurately calculate the switching losses [26, 27].

In the Matlab R2019a environment using blocks from the Simulink / Simscape library the scheme of the SIEMENS SINAMICS G110 frequency converter is developed, which is shown in Fig. 3.

The model contains the following blocks:

- block rectifier on diodes *VD7…VD10*, including a smoothing filter on the capacitor *C1*;
- unit of autonomous three-phase bridge voltage inverter on six IGBT / diode-transistors *VT1* (*VD1*)…*VT6* (*VD6*);
- unit for calculating the loss in the rectifier and inverter;
- load unit;
- a set of measuring instruments.

The method of approximation determines the mathematical functions that most accurately describe the energy graphs of the dependences $V_{ce}\,(I_c)$, $V_f\,(I_f)$, $E_{on}\,(I_c)$, $E_{off}\,(I_c)$, $E_{rec}\,(I_c)$ [28, 29].

Using this calculation method, it is possible to determine the static losses in the uncontrolled rectifier, static and dynamic losses in IGBT-transistors and reverse diodes AVI, and in general it is possible to quantify the efficiency of the frequency converter [30, 31].

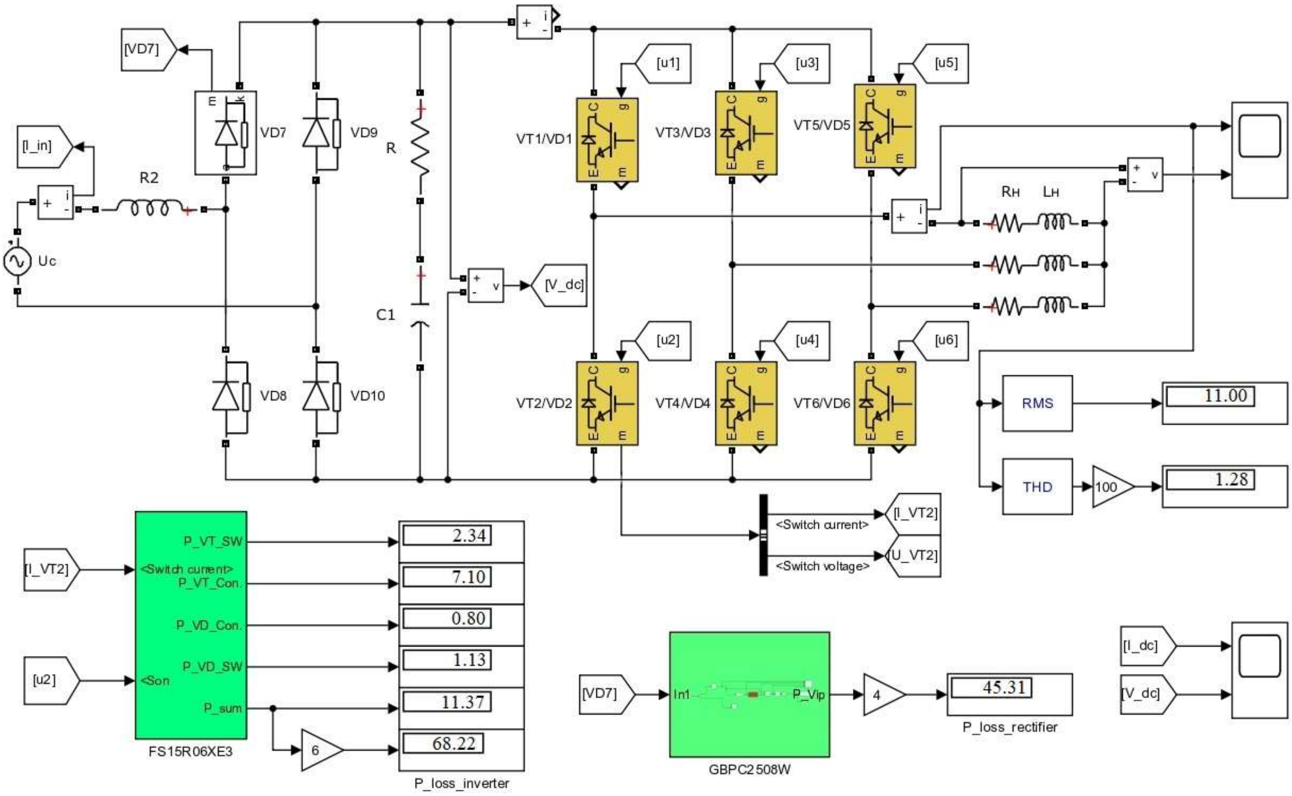


Figure 3 – Model of the frequency converter SIEMENS SINAMICS G110

After approximation of power loss graphs of diode uncontrolled rectifier type GBPC2508W and IGBT-transistor module type FS15R06XE3 expressions were obtained. Equation for diode uncontrolled rectifier type GBPC2508W:

$$U_F(I_F) = 0.0277 \cdot \left(\frac{I_F}{100}\right)^5 - 0.2812 \cdot \left(\frac{I_F}{100}\right)^4 +$$

$$+0.9917 \cdot \left(\frac{I_F}{100}\right)^3 - 1.4921 \cdot \left(\frac{I_F}{100}\right)^2 + 1.6057 \cdot \left(\frac{I_F}{100}\right) + 0.6551. \tag{4}$$

Equation for IGBT-transistor module type FS15R06XE3:

$$U_{CE}(I_C) = -102775 \cdot \left(\frac{I_C}{100}\right)^6 + 98467 \cdot \left(\frac{I_C}{100}\right)^5 - 36327 \cdot \left(\frac{I_C}{100}\right)^4 +$$

$$+6505.8 \cdot \left(\frac{I_C}{100}\right)^3 - 590.76 \cdot \left(\frac{I_C}{100}\right)^2 + 32.772 \cdot \left(\frac{I_C}{100}\right) + 0.3152; \tag{5}$$

$$U_F(I_F) = -72672 \cdot \left(\frac{I_F}{100}\right)^6 + 71308 \cdot \left(\frac{I_F}{100}\right)^5 - 27122 \cdot \left(\frac{I_F}{100}\right)^4 +$$

$$+5045.3 \cdot \left(\frac{I_F}{100}\right)^3 - 481.84 \cdot \left(\frac{I_F}{100}\right)^2 + 27.018 \cdot \left(\frac{I_F}{100}\right) + 0.4514; \tag{6}$$

$$E_{on}(I_C) = 4.8894 \cdot \left(\frac{I_C}{100}\right)^4 + 7.928 \cdot \left(\frac{I_C}{100}\right)^3 + 0.0715 \cdot \left(\frac{I_C}{100}\right)^2 + 1.8573 \cdot \left(\frac{I_C}{100}\right) + 0.0486; \quad (7)$$

$$E_{off}(I_C) = -15.198 \cdot \left(\frac{I_C}{100}\right)^4 + 16.984 \cdot \left(\frac{I_C}{100}\right)^3 - 8.0363 \cdot \left(\frac{I_C}{100}\right)^2 + 3.6428 \cdot \left(\frac{I_C}{100}\right) + 0.0456; \quad (8)$$

$$E_{rec}(I_F) = 5,4932 \cdot \left(\frac{I_F}{100}\right)^3 - 5,7025 \cdot \left(\frac{I_F}{100}\right)^2 + 2,6764 \cdot \left(\frac{I_F}{100}\right) + 0,0792. \quad (9)$$

The block for calculating the power losses of AVI by the method of approximation of loss graphs is shown in Fig. 4, 5.

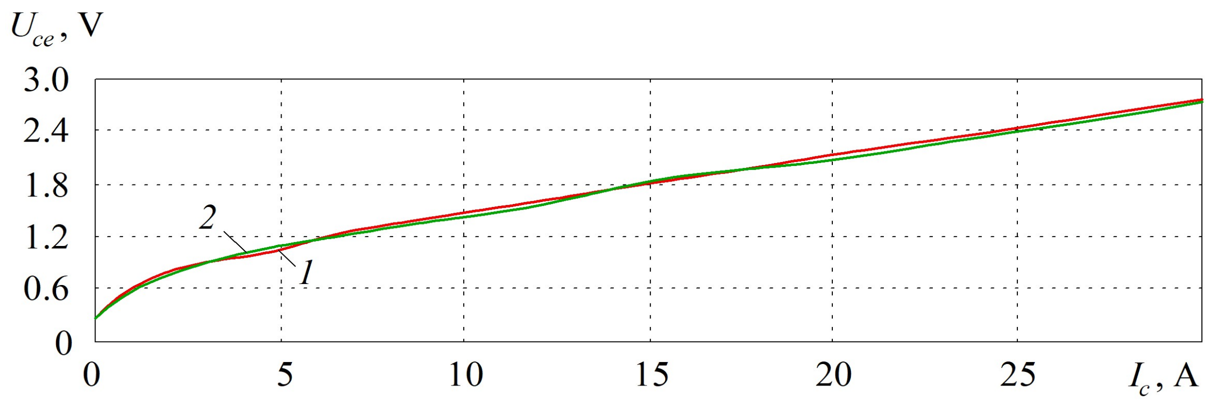


Figure 4 – Saturation voltage of the collector-emitter of the power transistor type FS15R06XE3: *1* – documentation; *2* – approximation

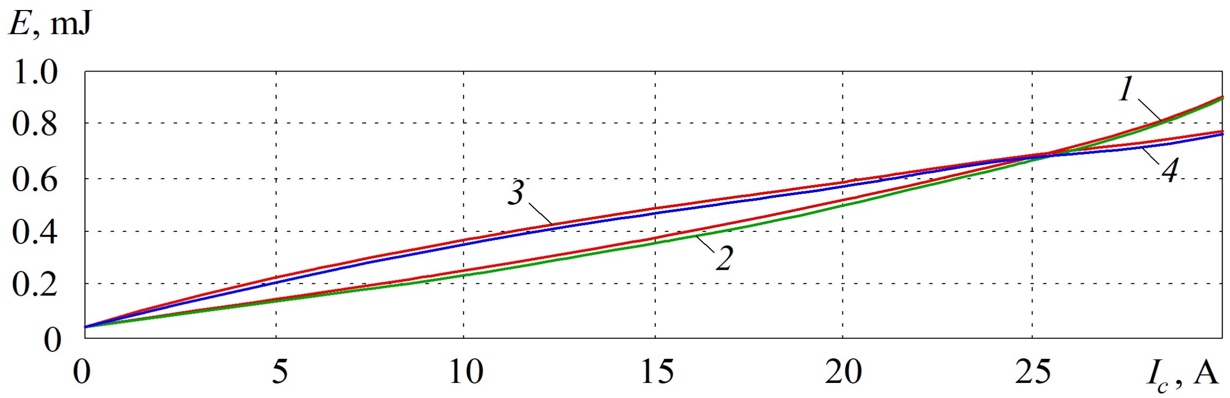


Figure 5 – Power switching characteristics of power transistor type FS15R06XE3: *1* – E_{on} (documentation); *2* – E_{on} (approximation); *3* – E_{off} (documentation); *4* – E_{off} (approximation)

The obtained mathematical dependences quite accurately describe the power graphs of power losses of the diode uncontrolled rectifier and IGBT-transistor module [32, 33].

The block model for calculating the power loss of the reverse diode of the IGBT-transistor module type FS15R06XE3 is shown in Fig. 6.

The control voltage and current of the transistor are used to calculate the static and dynamic power losses of the IGBT-transistor [34, 35].

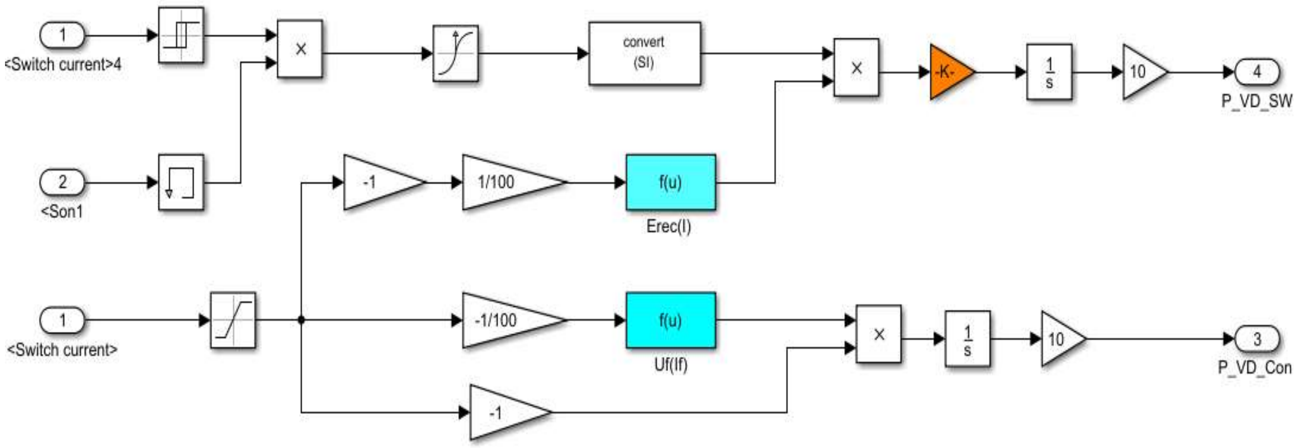


Figure 6 – Block model for calculating the power loss of the reverse diode of the IGBT transistor module type FS15R06XE3

The block model for calculating the power loss of the IGBT-transistor module type FS15R06XE3 is shown in Fig. 7.

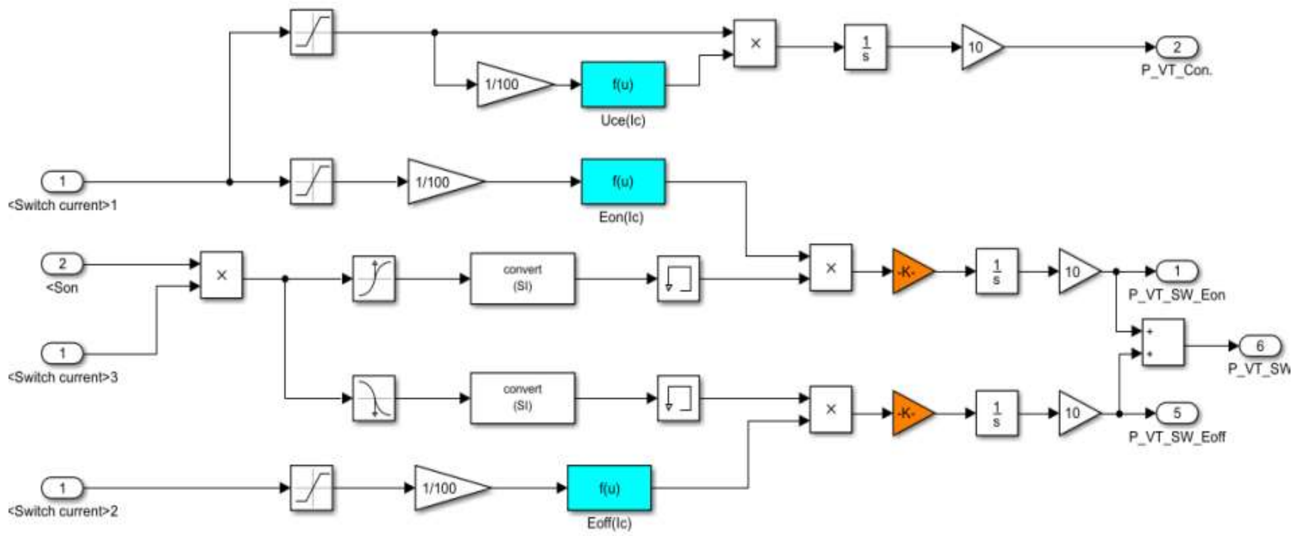


Figure 7 – Block model for calculating the power loss of the IGBT-transistor module type FS15R06XE3

The results of modeling static losses are shown in Fig. 8, and dynamic losses – in Fig. 9. As can be seen from the graphs, the on and off energies depend on the magnitude of the transistor current. To simulate dynamic losses, it is necessary to use the modeling method with a constant calculation step.

To verify the developed model in Matlab, which calculates power losses, a comparison was made with such programs as SemiSel and MelcoSim [36, 37]. The developed method of determination of power losses in power IGBT-transistors is checked. A comparative calculation of power losses using MelcoSim 5.1 for a three-level stand-alone voltage inverter with *RL* load, as well as the calculation of power losses performed in Matlab using the described methods.

The presented methods for calculating power losses in the frequency converter are implemented in Matlab / Simulink, compare the simulation results with data obtained using the online tool Semikron SemiSel at www.Semikron.com and using the program MelcoSim 5.4, which are used as a reference test. The interface of the MelcoSim 5.4 program is shown in Fig. 10.

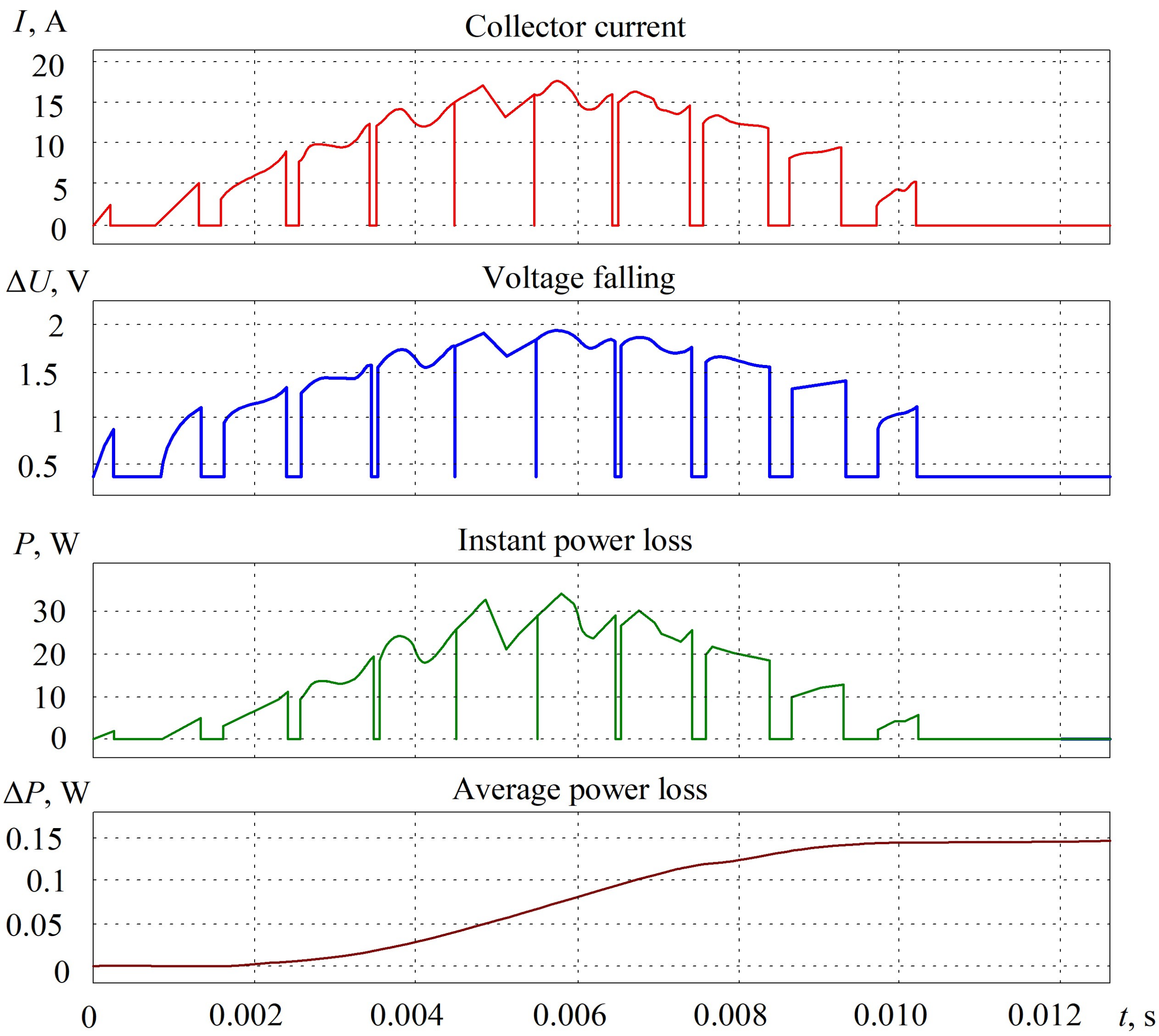


Figure 8 – The results of modeling the static losses of the IGBT-transistor module type FS15R06XE3

The results of the calculation of the loss in the uncontrolled rectifier are given in Table 4, which compares the calculation errors between the online tool Semikron SemiSel and Matlab Simulink.

Table 4

The results of the calculation of power losses in the uncontrolled rectifier type SKKE 15/08

Parameter	Matlab Simulink, W	Semikron SemiSel, W	Error, %
Static losses of the rectifier	24.66	23.66	4.05

The comparison error is 4.05 %, which is an indicator of the adequacy of the model in Matlab / Simulink.

The comparison and verification of the calculation of power losses in the AVI between the programs Matlab / Simulink and MelcoSim 5.4 were also performed. Analysis of the convergence of the calculation results in the programs Matlab / Simulink and MelcoSim 5.4 are given in Table 5.

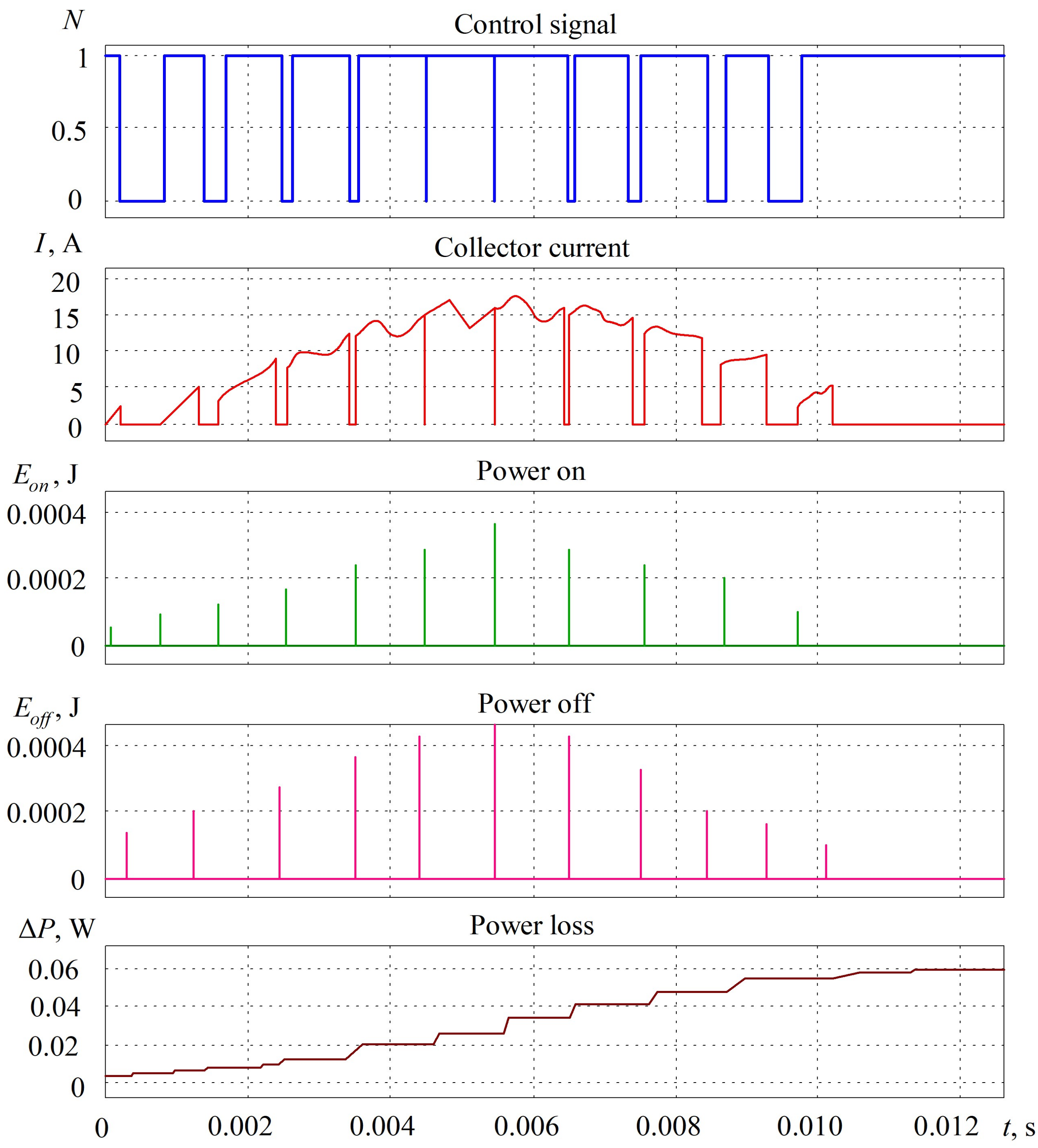


Figure 9 – The results of modeling the static losses of the IGBT-transistor module type FS15R06XE3

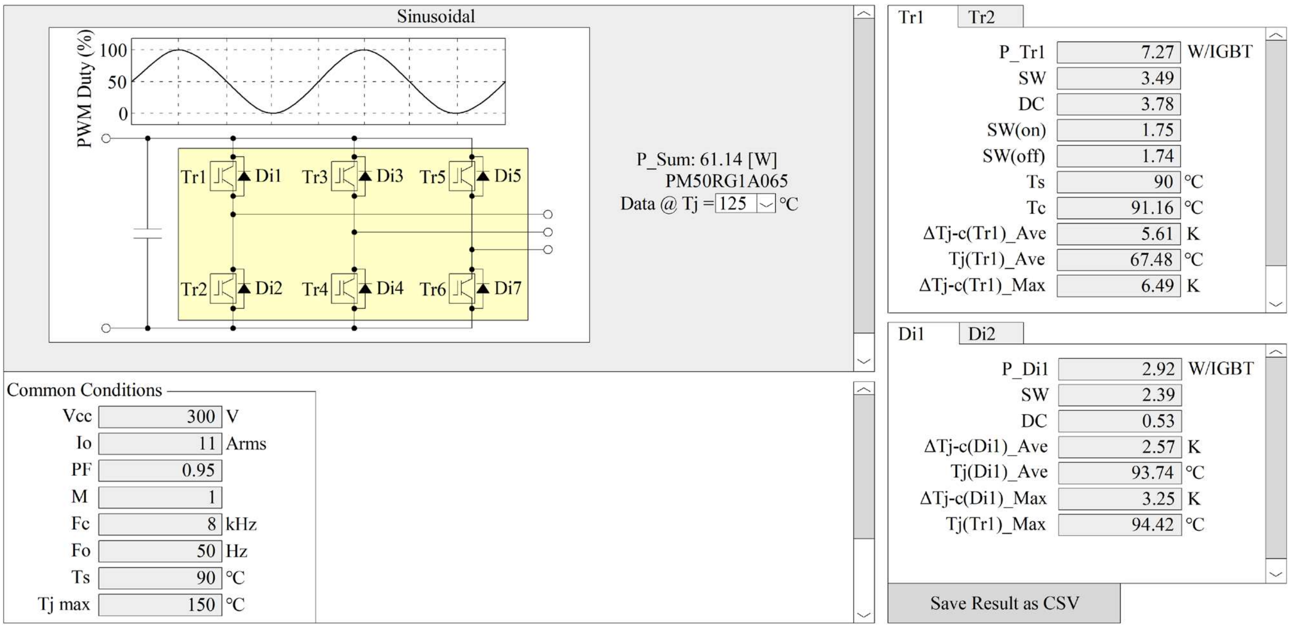


Figure 10 – MelcoSim 5.4 software interface

Table 5

The results of the calculation of power losses in the IGBT-transistor type PM50RG1A065

Parameter	Matlab Simulink, W	MelcoSim 5.4, W	Error, %
Static transistor losses	3.91	3.78	3.32
Dynamic transistor losses	3.62	3.49	3.59
Static losses in the reverse diode	2.49	2.39	4.01
Dynamic losses in the reverse diode	0.55	0.53	3.63

The results of the comparison showed that the discrepancy between the calculation of power losses in the developed model Matlab / Simulink and the calculation performed by the specialized program MelcoSim 5.4, does not give more than 4.1 %.

In the Table 6 shows a comparison between the losses obtained during physical simulation in Matlab / Simulink and the losses reported in the documentation of the frequency converter SIEMENS SINAMICS G110 with a power of 1.5 kW.

Table 6

The results of the calculation of power losses frequency converter in SIEMENS SINAMICS G110 with a capacity of 1.5 kW

Parameter	Documentation frequency converter, W	Matlab Simulink, W	Error, %
Total losses frequency converter GBPC2508W, W	118	113.53 + losses on active resistance	3.78

The results of the comparison between the losses are very close. The comparison error is only 3.78 %, which is an indicator of the sufficient adequacy of the developed model of the frequency converter in Matlab / Simulink.

Summary and conclusions. Losses in the rectifier circuit and in the AVI circuit were determined by the simulation method. A compromise has been reached between the accuracy of modeling in Matlab and programs such as SemiSel and MelcoSim.

Practical methods for calculating losses while maintaining high accuracy were chosen. The reliability and usefulness of the proposed method of modeling the calculation of power losses is assessed by comparing the results given in the documentation of the frequency converter SIEMENS SINAMICS G110 and physical modeling in the MATLAB environment.

The method of simulation modeling is presented, which allows to estimate power losses in power semiconductor converters. This method is used to estimate the power loss in the frequency converter SIEMENS SINAMICS G110 and gave an error of 3…4 % relative to the data stated by the manufacturer. A block of the model is calculated that calculates the loss of conductivity in the uncontrolled rectifier and the losses that occur in the AVI of the frequency converter. This method of calculating power losses can be used in the design and analysis of frequency converters of any power.

To calculate the power losses by the approximation method, mathematical equations are determined that most accurately describe the energy graphs of the dependences $V_{ce}(I_c)$, $V_f(I_f)$, $E_{on}(I_c)$, $E_{off}(I_c)$, $E_{rec}(I_c)$. The obtained mathematical equations quite accurately describe the graphs of power losses.

References:

1. Побєдаш К. К., Святненко В. А. (2017). Силові напівпровідникові прилади і перетворювачі електричної енергії: навч. посіб. Київ: КПІ ім. Ігоря Сікорського, 244 с.

2. Шавьолкін О. О. (2015). Силові напівпровідникові перетворювачі енергії: навч. посібник. Харків: ХНУМГ ім. О. М. Бекетова, 403 с.

3. Zhemerov G. G., Krylov D. S. (2018). Concept of construction of power circuits of a multilevel modular converter and its transistor modules in Electrical Engineering & Electromechanics, no. 6, pp. 26–32. DOI: 10.20998/2074-272X.2018.6.03.

4. Nerubatskyi V. P., Plakhtii O. A., Tugay D. V., Hordiienko D. A. (2021). Method for optimization of switching frequency in frequency converters. Scientific bulletin of National mining university, no. 1 (181), pp. 103–110. DOI: 10.33271/nvngu/2021-1/103.

5. Карпова Л. В., Гула І. В. (2015). Застосування IGBT транзисторів для задач керування у силовій електроніці. Вимірювальна та обчислювальна техніка в технологічних процесах, № 2, С. 62–67.

6. Nerubatskyi V., Plakhtii O., Hordiienko D., Khoruzhevskyi H. (2020). Study of energy parameters in alternative power source microgrid systems with multi-level inverters. International scientific journal «Industry 4.0», vol. 5, issue 3, pp. 118–121.

7. Vamanan N., John V. (2018). Dual-Comparison One-Cycle Control for Single-Phase Bidirectional Power Converters. IEEE Transactions on Industry Applications, vol. 54, no. 5, pp. 4621–4631. DOI: 10.1109/TIA.2018.2836359.

8. Нерубацький В. П., Плахтій О. А., Кавун В. Є., Машура А. В.,

Гордієнко Д. А., Цибульник В. Р. (2018). Аналіз показників енергоефективності автономних інверторів напруги з різними типами модуляції. Збірник наукових праць Українського державного університету залізничного транспорту, 180, с. 106–120.

9. Нерубацький В. П., Плахтій О. А., Карпенко Н. П., Гордієнко Д. А., Цибульник В. Р. (2019). Аналіз енергетичних процесів у семирівневому автономному інверторі напруги при різних алгоритмах модуляції. Інформаційно-керуючі системи на залізничному транспорті, № 5, с. 8–18. DOI: 10.18664/ikszt.v24i5.181286.

10. Нерубацький В. П., Плахтій О. А., Цибульник В. Р., Гордієнко Д. А., Хоружевський Г. А. (2020). Аналіз показників енергоефективності автономних інверторів напруги з імпедансною і квазіімпедансною ланками у вхідному колі при застосуванні різних алгоритмів модуляції. Інформаційно-керуючі системи на залізничному транспорті, т. 25, № 3, с. 19–31. DOI: 10.18664/ikszt.v25i3.214089.

11. Plakhtii O. A., Nerubatskyi V. P., Kavun V. Ye., Hordiienko D. A. (2019). Active single-phase four-quadrant rectifier with improved hysteresis modulation algorithm. Scientific Bulletin of National Mining University, no. 5 (173), pp. 93–98. DOI: 10.29202/nvngu/2019-5/16.

12. Плахтій О. А., Нерубацький В. П., Гордієнко Д. А., Цибульник В. Р. (2019). Аналіз енергоефективності трирівневих автономних інверторів напруги в режимі перемодуляції. Інформаційно-керуючі системи на залізничному транспорті, № 4, с. 3–12. DOI: 10.18664/ikszt.v0i4.177089.

13. Kim Y., Oh C., Sung W., Lee B. (2017). Topology and control scheme of OBC-LDC integrated power unit for electric vehicles. IEEE Trans. Power Electron, vol. 32, pp. 1731–1743.

14. Liu T., Feng Y., Ning R., Wong T. T., Shen Z. J. (2017). Extracting parasitic inductances of IGBT power modules with two-port S-parameter measurement. 2017 IEEE Transportation Electrification Conference and Expo (ITEC), pp. 281–287.

15. Kumar P., Bhowmick B. (2018). A physics-based threshold voltage model for hetero-dielectric dual material gate Schottky barrier MOSFET. Int. J. Numer. Model, vol. 31, pp. 1–11.

16. Nerubatskyi V., Plakhtii O., Hordiienko D., Mykhalkiv S., Ravlyuk V. (2021). A method for calculating the parameters of the sine filter of the frequency converter, taking into account the criterion of starting current limitation and pulse-width modulation frequency. Eastern-European Journal of Enterprise Technologies, vol. 1, no. 8 (109), pp. 6–16. DOI: 10.15587/1729-4061.2021.225327.

17. Boram Y., Yeong-Hun P., Ji-Woon Y. (2020). Physics-based compact model of transient leakage current caused by parasitic bipolar junction transistor in gate-all-around MOSFETs. Solid State Electron, vol. 164, pp. 1–12.

18. Safaee A., Jain P., Bakhshai A. (2016). A ZVS pulsewidth modulation full-bridge converter with a low-RMS-current resonant auxiliary circuit. IEEE Trans. Power Electron, vol. 31, pp. 4031–4047.

19. Mali S. M., Patil Dr. B. (2018). THD Minimization in Multilevel Inverter Using Optimization Approach. International Journal of Engineering Research &

Technology (IJERT), vol. 7, issue 6, pp. 97–100.

20. Plakhtii O. A., Nerubatskyi V. P., Hordiienko D. A., Khoruzhevskyi H. A. (2020). Calculation of static and dynamic losses in power IGBT-transistors by polynomial approximation of basic energy characteristics. Scientific bulletin of National mining university, no. 2 (176), pp. 82–88. DOI: 10.33271/nvngu/2020-2/082.

21. Gervasio F., Mastromauro R., Liserre M. (2015). Power losses analysis of two-levels and three-levels PWM inverters handling reactive power. 2015 IEEE International Conference on Industrial Technology (ICIT), pp. 1123–1128. DOI: 10.1109/icit.2015.7125248.

22. Rainer K., Alberto C. (2016). A physics-based compact model of SiC power MOSFETs. IEEE Trans. Power Electron, vol. 31, pp. 5863–5870.

23. Jin M., Gao Q., Wang Y., Xu D. (2018). A temperature-dependent sic MOSFET modeling method based on MATLAB/Simulink. IEEE Access, vol. 6, pp. 4497–4505.

24. Xie L., Ruan X., Ye Z. (2018). Reducing common mode noise in phase-shifted full-bridge converter. IEEE Trans. Ind. Electron, vol. 65, pp. 7866–7877.

25. Plakhtii O., Nerubatskyi V., Sushko D., Hordiienko D., Khoruzhevskyi H. (2020). Improving the harmonic composition of output voltage in multilevel inverters under an optimum mode of amplitude modulation. Eastern-European Journal of Enterprise Technologies, vol. 2, no. 8 (104), pp. 17–24. DOI: 10.15587/1729-4061.2020.200021.

26. Bashir S. B., Memon Z. A. (2018). An Improved Voltage Balancing Method for Grid Connected PV System Based on MMC Under Different Irradiance Conditions. 2018 IEEE 61st International Midwest Symposium on Circuits and Systems (MWSCAS), pp. 865–868. DOI: 10.1109/MWSCAS.2018.8623947.

27. Ahmed M. R., Todd R., Forsyth A. J. (2017). Predicting SiC MOSFET behavior ender hard-switching, soft-switching, and false turn-on conditions. IEEE Trans. Ind. Electron, vol. 64, pp. 9001–9011.

28. Dias R. A., Lira G. R., Costa E. G., Ferreira R. S., Andrade A. F. (2018). Skin effect comparative analysis in electric cables using computational simulations. 2018 Simposio Brasileiro de Sistemas Eletricos (SBSE). DOI: 10.1109/sbse.2018.8395687.

29. Wang Q., Cheng M., Zhang B. (2015). An improved topology for the current fed parallel resonant half bridge circuits used in fluorescent lamp electronic ballasts. J. Power Electron, vol. 15, pp. 567–575.

30. Bharadwaj P., John V. (2019). Subcell Modeling of Partially Shaded Photovoltaic Modules. IEEE Transactions on Industry Applications, vol. 55, no. 3, pp. 3046–3054. DOI: 10.1109/TIA.2019.2899813.

31. Borrega M., Marroyo L., Gonzalez R., Balda J., Agorreta J. (2013). Modeling and control of a master-slave PV inverter with n-paralleled inverters and three-phase three-limb inductors. IEEE Trans. Power Electron, vol. 28, no. 6, pp. 2842–2855.

32. Liu T., Wong T. T., Shen Z. J. (2018). A new characterization technique for extracting parasitic inductances of sic power MOSFETs in discrete and module packages based on two-port s-parameters measurement. IEEE Trans. Power Electron,

CONTENTS/СОДЕРЖАНИЕ

Mechanical engineering and machinery
Машиностроение и машиноведение

http://www.moderntechno.de/index.php/meit/article/view/meit16-01-007 **6**

THE NUMERICAL SIMULATION OF THERMO-ELASTO-PLASTIC STATE OF COMPOSITES

ЧИСЛОВЕ МОДЕЛЮВАННЯ ТЕРМОПРУЖНОПЛАСТИЧНОГО СТАНУ КОМПОЗИТІВ

Karvatskii A. Ya. / Карвацький А. Я., Mikulionok I. O. / Мікульонок І. О., Leleka S.V. / Лелека С.В., Vytvytskyi V.M. / Витвицький В.М., Solovei V.V. / Соловей В.В.

http://www.moderntechno.de/index.php/meit/article/view/meit16-01-033 **18**

THERMAL PROTECTION INSULATION IN THE LINING OF THE ROTARY KILNS

Shvachko D.G., Shcherbina V. Yu., Borshchik S.A.

http://www.moderntechno.de/index.php/meit/article/view/meit16-01-046 **24**

MEASURING THE VISCOSITY OF LIQUIDS IN A CONICAL VISCOMETER

ВИМІРЮВАННЯ В'ЯЗКОСТІ РІДИН В КОНІЧНОМУ ВІСКОЗИМЕТРІ

Andreiev I. A. / Андреєв І. А., Koval V. O. / Коваль В. О.

http://www.moderntechno.de/index.php/meit/article/view/meit16-01-126 **29**

REGENERATIVE HEAT EXCHANGER WITH NOZZLE FROM THE NET OF A CANVAS WEAVING

РЕГЕНЕРАТИВНИЙ ТЕПЛООБМІННИК З НАСАДКОЮ ІЗ СІТКИ ПОЛОТНЯНОГО ПЛЕТІННЯ

Dvoinos Y.H. / Двойнос Я.Г., Yevziutin Pavlo / Євзютін Павло

http://www.moderntechno.de/index.php/meit/article/view/meit16-01-127 **34**

COEFFICIENTS OF CRITERION EQUATION OF HEAT RELEASE GAS TO THE CORRUGATED PLATE

КОЕФІЦІЄНТИ КРИТЕРІАЛЬНОГО РІВНЯННЯ ТЕПЛОВІДДАЧІ ГАЗУ ДО ГОФРОВАНОЇ ПЛАСТИНИ

Dvoinos Y.H. / Двойнос Я.Г., Italiantsev O.I. / Італьянцев О.І.

http://www.moderntechno.de/index.php/meit/article/view/meit16-01-128 **39**

ESTIMATION OF SENSITIVITY OF DAMPING ABILITY OF STRUCTURES

ОЦІНКА ЧУТЛИВОСТІ ДЕМПФУЮЧОЇ ЗДАТНОСТІ КОНСТРУКЦІЙ

Bovsunovsky A.P. / Бовсуновський А.П., Nosal O.Yu. / Носаль О.Ю.

Electrical engineering
Электротехника

http://www.moderntechno.de/index.php/meit/article/view/meit16-01-035 **44**

SIMULATION OF POWER LOSSES IN THE FREQUENCY CONVERTER

МОДЕЛИРОВАНИЕ ПОТЕРЬ МОЩНОСТИ В ПРЕОБРАЗОВАТЕЛЕ ЧАСТОТЫ

Nerubatskyi V. P. / Нерубацкий В. П., Plakhtii O. A. / Плахтий А. А. Hordiienko D. A. / Гордиенко Д. А., Karpenko N. P. / Карпенко Н. П.