Національний технічний університет України
«КИЇВСЬКИЙ ПОЛІТЕХНІЧНИЙ ІНСТИТУТ
імені ІГОРЯ СІКОРСЬКОГО»

Department of Automation of Electromechanical Systems and Electric Drive FEA

# ELECTROMECHANICAL SYSTEMS OF ELECTRIC VEHICLES

## Work program of the discipline (Syllabus)

| Details of the discipline | |
|---|---|
| **Level of higher education** | ***Second (master's)*** |
| **Branch of knowledge** | *14 "Electrical Engineering"* |
| **Specialty** | *141 "Electric power, electrical engineering and electromechanics"* |
| **Educational program** | *Electromechanical automation systems, electric drive and electric mobility* |
| **Discipline status** | *Normative* |
| **Form of study** | *Eye (day)* |
| **Year of preparation, semester** | *And the course, the spring semester* |
| **The scope of discipline** | *180 hours / 6 ECTS credits* |
| **Semester control / control measures** | *Offset / MCR* |
| **Timetable** | *http://rozklad.kpi.ua* |
| **Language of instruction** | *Ukrainian / English* |
| **Information about the course leader / teachers** | Lecturer: *Dr. Serhii Kovbasa, 0674351881*<br>Practical: *Dr. Serhii Kovbasa, 0674351881*<br>Laboratory: *Dr. Serhii Kovbasa, 0674351881* |
| **Course placement** | |

**Curriculum**

### 1. Description of the discipline, its purpose, subject of study and learning outcomes

*The syllabus of the discipline "Electromechanical systems of electric vehicles" is compiled in accordance with the educational program "Electric power, electrical engineering and electromechanics" training masters 141 - Electric power, electrical engineering and electromechanics.*

**The purpose of the discipline** *there is a formation in students of the following abilities: ability to apply knowledge in practice situations; ability to learn and master modern knowledge; ability to identify and assess risks.*

**The subject of the discipline** *- electromechanical systems of electric vehicles, which include new electromechanical converters, means of power electronics, methods of control and signal processing, as well as issues of modern research in the field of electromechanical systems of electric vehicles.*

***Program learning outcomes:***

*Competencies:(FC2) the ability to develop and implement measures to improve the reliability, efficiency and safety in the design and operation of equipment and facilities of electricity, electrical*

*engineering and electromechanics; (FC3) the ability to analyze technical and economic indicators and examination of design decisions in the field of power engineering, electrical engineering and electromechanics; (FC8) the ability to demonstrate awareness and ability to use regulations, norms, rules and standards in power engineering, electrical engineering and electromechanics; (FC9) the ability to use software for computer modeling, computer-aided design, automated production and automated development or design of elements of electrical, electrical and electromechanical systems;*

*Skills:(PH01) to reproduce processes in electric power, electrotechnical and electromechanical systems at their computer modeling; (PH04) to reconstruct existing electrical networks, stations and substations, electrical and electromechanical complexes and systems in order to increase their reliability, efficiency operation and life extension; (PH06) to search for sources of resource support for additional training, research and innovation; (PH11) to communicate freely orally and in writing in state and foreign languages on modern scientific and technical problems of electric power, electrical engineering and electromechanics; (PH14) to master new versions or new software designed for computer modeling of objects and processes in electrical, electrical and electromechanical systems;*

**2. Prerequisites and postrequisites of the discipline (place in the structural and logical scheme of education according to the relevant educational program)**

*To successfully master the discipline, the student must have a "Practical course of foreign language business communication", as much of the latest technology is described in the scientific literature in English. Competences, knowledge and skills acquired in the process of studying the credit module are necessary for further internship for a master's thesis.*

**3. The content of the discipline**

*The discipline is structurally divided into 3 sections, namely:*

***Section 1. General information about electric vehicles***

*Topic 1.1. Introduction. History of ETZ development. Impact on the environment and development prospects.*

*Topic 1.2. Types and classification of electric vehicles. ETZ with battery or supercapacitor power supply. Hybrid vehicles. Ground wheeled, air, surface and underwater ETZ. Basic types and classification.*

*Topic 1.3. Theoretical bases of formation of traction and braking forces in wheeled vehicles.*

*Topic 1.4. Fundamentals of internal combustion engines and transmissions.*

***Section 2. Electric vehicles with kinematic rolling steam***

*Topic 2.1. Functional diagram of ETZ with battery or supercapacitor power supply. Features of operation of fully electric vehicles.*

*Topic 2.2. General information about batteries and supercapacitors. Mathematical models and characteristics of energy storage devices.*

*Topic 2.3. Operation of electromechanical ETZ systems in the recovery mode. The problem of conservation and use of energy recovery.*

*Topic 2.4. Hybrid vehicles. Classification, basic schemes and modes of operation.*

*Topic 2.5. Electric vehicles powered by fuel cells.*

*Topic 2.6. Features of charging infrastructure for electric vehicles.*

*Topic 2.7. Electromechanical systems of trolleybuses.*

*Topic 2.8. Electromechanical systems of tram cars.*

*Topic 2.8. Electromechanical systems of subway cars.*

*Topic 2.9. Algorithms for controlling the coordinates of traction motors of wheeled ETZ*

***Section 3. Development of electromechanical systems of electric vehicles***

*Topic 3.1. Functional diagram of a vector-controlled asynchronous electric drive.*

*Topic 3.2. Current and voltage measurement*

*Topic 3.3 Measuring angular velocity and position using a photo of a pulse speed sensor and a resolver.*

*Topic 3.4. Design of the power part of the frequency converter*

*Topic 3.5. Designing the hardware of the control controller*

*Topic 3.6. Development of the general scheme of the converter*

*Topic 3.7. Power supplies for own needs. DC-DC converters*

*Topic 3.8. General concepts of electromagnetic compatibility. Rules of location of power and signal conductors. Methods of increasing noise immunity and protection of elements of electromechanical systems.*

**4. Training materials and resources**

*1. Zagirnyak MV, Klepikov VB, Kovbasa SM, Mikhalsky VM, Peresada SM, Sadovoy OV, Shapoval IA Energy efficient electromechanical systems for a wide range of technological purposes. Kyiv: NAS of Ukraine, 2018. 310 p.*

*2. Methods of robust adaptive control of electromechanical systems with increased dynamic and energy performance: GDR report. NTUU "KPI". № DP 0115U000381. Kyiv, 2017. 506 p.*

*3. Development of energy-efficient electromechanical electric bus system based on adaptive vector-controlled asynchronous electric drive with battery-supercapacitor power supply: report on GDR / NTUU "KPI". № DP 0117U004284. Kyiv, 2018. Volume 1. 472 p.*

*4. M. Ehsani, Y. Gao, S. Longo, KM Ebrahimi Modern Electric, Hybrid Electric, and Fuel Cell Vehicles. Third edition. - CRC Press, 2018, –573p.*

*5. Kovbasa SM Development of the theory of gearless vector control of electromechanical systems with asynchronous motors .: Dis. Dr. tech. Science: 05.09.03. Kiev. 2020*

*6. J. Larminie, J. Lowry Electric vehicle technology explained. –WILEY. 2012. –328p.*

*7. A. Emadi Handbook of Automotive Power Electronics and Motor Drives. –CRC Press. 2005. –668p.*

*8. Theory of electric drive / Ed. M.G. Popovich.- K .: Higher school, 1993.-494 p.*

**Educational content**

**5. Methods of mastering the discipline (educational component)**

*Lectures*

| *№ s / n* | *The title of the lecture topic and a list of key issues (list of teaching aids, links to information sources)* |
|---|---|
| *1* | *Topic 1.1. Introduction. History of ETZ development. Impact on the environment and development prospects.* |
| *2* | *Topic 1.2. Types and classification of electric vehicles. ETZ with battery or supercapacitor power supply. Hybrid vehicles. Ground wheeled, air, surface and underwater ETZ. Basic types and classification.* |
| *3* | *Topic 1.2. Types and classification of electric vehicles. ETZ with battery or supercapacitor power supply. Hybrid vehicles. Ground wheeled, air, surface and underwater ETZ. Basic types and classification.* |

| | |
|---|---|
| 4 | *Topic 1.3. Theoretical bases of formation of traction and braking forces in wheeled vehicles.* |
| 5 | *Topic 1.4. Fundamentals of internal combustion engines and transmissions.* |
| 6 | *Topic 2.1. Functional diagram of ETZ with battery or supercapacitor power supply. Features of operation of fully electric vehicles.* |
| 7 | *Topic 2.2. General information about batteries and supercapacitors. Mathematical models and characteristics of energy storage devices.* |
| 8 | *Topic 2.3. Operation of electromechanical ETZ systems in the recovery mode. The problem of conservation and use of energy recovery.* |
| 9 | *Topic 2.3. Operation of electromechanical ETZ systems in the recovery mode. The problem of conservation and use of energy recovery.* |
| 10 | *Topic 2.4. Hybrid vehicles. Classification, basic schemes and modes of operation.* |
| 11 | *Topic 2.4. Hybrid vehicles. Classification, basic schemes and modes of operation.* |
| 12 | *Topic 2.5. Electric vehicles powered by fuel cells.* |
| 13 | *Topic 2.6. Features of charging infrastructure for electric vehicles.* |
| 14 | *Topic 2.7. Electromechanical systems of trolleybuses.* |
| 15 | *Topic 2.8. Electromechanical systems of tram cars.* |
| 16 | *Topic 2.8. Electromechanical systems of subway cars.* |
| 17 | *Topic 2.9. Algorithms for controlling the coordinates of traction motors of wheeled ETZ* |
| 18 | *Topic 2.9. Algorithms for controlling the coordinates of traction motors of wheeled ETZ* |
| 19 | *Topic 3.1. Functional diagram of a vector-controlled asynchronous electric drive.* |
| 20 | *Topic 3.2. Current and voltage measurement* |
| 21 | *Topic 3.3 Measuring angular velocity and position using a photo pulse speed sensor and resolver* |
| 22 | *Topic 3.4. Design of the power part of the frequency converter* |
| 23 | *Topic 3.4. Design of the power part of the frequency converter* |
| 24 | *Topic 3.5. Designing the hardware of the control controller* |
| 25 | *Topic 3.6. Development of the general scheme of the converter.* |
| 26 | *Topic 3.7. Power supplies for own needs. DC-DC converters.* |
| 27 | *Topic 3.8. General concepts of electromagnetic compatibility. Rules of location of power and signal conductors. Methods of increasing noise immunity and protection of elements of electromechanical systems.* |

*Practical training*

| *№ s / n* | *The name of the topic of the lesson and a list of main questions* |
|---|---|
| 1 | *Issuance of a task for a course project* |
| 2 | *Calculation of engine power of an electric vehicle* |
| 3 | *Calculation of battery power and configuration* |
| 4 | *Calculation of capacity and battery configuration of supercapacitors* |
| 5 | *Calculation of the power reserve of an electric vehicle with different configurations of energy exchange* |
| 6 | *Calculation of the main elements of the power converter of electric vehicles.* |
| 7 | *Calculation of the main elements of the control controller of the traction electric drive.* |
| 8 | *Acquaintance with prototypes of traction electric drives, experimental researches of their work.* |

| | |
|---|---|
| 9 | Modular control work |

Laboratory work

| № s / n | The name of the topic of the lesson and a list of main questions |
|---|---|
| 1 | Research of coordinate control systems of traction induction motors. |
| 2 | Research of coordinate control systems of traction synchronous motors. |
| 3 | Research on the operation of batteries and supercapacitors. |
| 4 | Investigation of energy efficient vector torque control systems for induction motors. |
| 5 | Research of features of measurement of angular velocity. |
| 6 | Research of features of formation of pulse-width modulation. |
| 7 | Research of features of measurement of signals of currents and voltages. |
| 8 | Study of the dynamics of an electric vehicle. |
| 9 | Investigation of energy exchange processes in hybrid power supplies. |

### 6. Independent work of student

| №з / п | Type of independent work | Number hours of CPC |
|---|---|---|
| 1 | Preparation for classroom classes | 65 |
| 3 | Preparation for MCR | 10 |
| 4 | Preparation for the test | 15 |

***6. Tests***

*The purpose of tests is to consolidate and test theoretical knowledge of the credit module, students gain practical skills for solving problems.*

*One modular control work (MCR) is carried out. The main options of tasks.*

*1. Explain the purpose of the blocks of the functional diagram of the chat converter.*

*2. To reveal the functional scheme and features of the electric car.*

*3. To reveal the functional scheme and features of the trolleybus.*

*4. To reveal the functional scheme and features of the tram car.*

*5. To reveal the functional scheme and features of the hybrid car.*

## Policy and control

### 7. Course policy (educational component)

*The system of requirements that the teacher puts before the student:*

- *rules for attending classes: in accordance with Order 1-273 of 14.09.2020, it is prohibited to assess the presence or absence of the applicant in the classroom, including the accrual of incentive or penalty points. According to the RSO of this discipline, points are awarded for the relevant types of educational activity in lectures and practical classes.*
- *rules of conduct in the classroom: the student has the opportunity to receive points for the relevant types of educational activities in lectures and practical classes provided by the RSO discipline. The use of means of communication to search for information on the teacher's Google*

*drive, on the Internet, in a distance course on the Sikorsky platform is carried out under the guidance of the teacher;*

- *policy of deadlines and rearrangements: if the student did not pass or did not appear at the MCR (without good reason), his result is estimated at 0 points. Interpretation of MCR results is not provided;*
- *Academic Integrity Policy: Code of Honor of the National Technical University of Ukraine "Kyiv Polytechnic Institute" https://kpi.ua/files/honorcode.pdf establishes general moral principles, rules of ethical conduct of individuals and provides a policy of academic integrity for people who work and study at the university, which they should be guided in their activities, including the study and preparation of control measures in the discipline "Electromechanical systems of electric vehicles";*
- *when using digital means of communication with the teacher (mobile communication, e-mail, correspondence on forums and social networks, etc.) it is necessary to adhere to generally accepted ethical norms, in particular to be polite and limit communication during the teacher's working hours.*

## 8. Types of control and rating system for evaluation of learning outcomes (RSO)

***Current control****: express survey, MCR, work in practical and laboratory classes.*
***Calendar control****: conducted twice a semester as a monitoring of the current state of compliance with the requirements of the syllabus.*
***Semester control:*** *test.*
***Conditions of admission to semester control****: semester rating more than 30 points.*
*Table of correspondence of rating points to grades on the university scale:*

| *Scores* | *Rating* |
|---|---|
| *95-100* | *Perfectly* |
| *85-94* | *Very good* |
| *75-84* | *Fine* |
| *65-74* | *Satisfactorily* |
| *60-64* | *Enough* |
| *Less than 60* | *Unsatisfactorily* |
| *Less than 30* | *Not allowed* |

*The overall rating of the student after the end of the semester consists of points obtained for:*

- *answers during express surveys at lectures;*
- *work in practical classes;*
- *performance and protection of laboratory works;*
- *performing modular control work (MCR).*

| *Express survey* | *Work on practical classes* | *Laboratory classes* | *MCR* |
|---|---|---|---|
| *27* | *9* | *36* | *28* |

***Answers during express surveys at lectures***

*Weight point 1. The maximum number of points in all lectures - 1 point * 27 = 27 points.*
***Evaluation criteria***

- *correct answers to some questions from the place - 1 point;*
- *partially correct answer - 0.5 points;*
- *wrong answer - 0 points;*

***Work on practical classes***

*Weight score -1. The maximum number of points in all classes - 1 point * 9 = 9 points.*

***Evaluation criteria***

- *independent problem solving, free possession of the topic of lesson -1;*
- *problem solving with the help of a teacher, possession of separate sections of the lesson topic - 0.5;*
- *unsatisfactory work in class - 0.*

***Laboratory work***

*Weight score -4.*

*The maximum number of points for all laboratory work -*
*4 points * 9 = 36 points.*

***Evaluation criteria***

- *full and timely performance of work - 2 points;*
- *incomplete performance of work - 1 point;*
- *timely defense of work at the next lesson with full answers to questions (up to 3 questions) - 2 points;*
- *untimely defense of work with complete answers to questions - 1 point;*
- *untimely defense of work and unsatisfactory answers to questions - 0 points.*

***Modular control work***

*Weight score MKR - 28.*

*The maximum score for MCR is 28.*

***Evaluation criteria***

- *complete answer to the question (more than 90% of the material) 25 - 28 points;*
- *incomplete answer to the question (from 50 to 90% of the material) - 14 - 24 points;*
- *the answer contains less than 50% of the required information - 0 points;*

*Calendar control is based on the current rating. The condition of positive attestation is the value of the current student rating not less than 50% of the maximum possible at the time of attestation.*

***Form of semester control - credit***

*The maximum amount of points is 100. A necessary condition for admission to the test is a complete syllabus of lectures, completed and defended laboratory work. To receive credit from the credit module "automatic" you must have a rating of at least 60 points, as well as the conditions of admission to credit.*

*Students who have a rating of less than 60 points at the end of the semester, as well as those who want to improve their score in the ECTS system, perform a test. In this case, the points scored by the student are canceled, and the grade for the test is final.*

*The test consists of two theoretical questions, one of which can be replaced by a problem.*

***Credit evaluation criteria***

*- "excellent", complete answer, not less than 95% of the required information (complete, error-free problem solving) - 95 - 100 points;*

*- "very good", a fairly complete answer, at least 85% of the required information or minor inaccuracies (complete problem solving with minor inaccuracies) - 85-94 points;*

*- "good", a sufficiently complete answer, at least 75% of the required information or minor inaccuracies (complete solution of the problem with minor inaccuracies) - 75-84 points;*

*- "satisfactory", incomplete answer, not less than 65% of the required information and some errors (the task is performed with certain shortcomings) - 65-74 points;*

*- "enough", incomplete answer, but not less than 60% of the required information and some errors (the task is performed with certain shortcomings) -60 - 64 points;*

*- "unsatisfactory", the answer does not meet the conditions for "satisfactory" - 0 points.*

## 9. Additional information on the discipline (educational component)

***List of topics that are submitted for semester control***

1. *Functional diagram of a vector-controlled asynchronous electric drive. Assignment of elements.*
2. *Functional diagram of a vector-controlled asynchronous electric drive. Job description.*
3. *The main differences between converter circuits for frequency and vector control systems.*
4. *Dependence of overload capacity of converters on the scope of their application.*
5. *Electromechanical trolleybus system with induction motor.*
6. *Electromechanical system of a tram car based on AC motors.*
7. *Electromechanical systems of subway cars.*
8. *Electromechanical systems of electric buses.*
9. *General information about energy storage devices of electric vehicles.*
10. *Hybrid power supplies for electric vehicles.*
11. *Fundamentals of the theory of movement of wheeled vehicles.*
12. *Modern electromechanical converters of electric vehicles.*
13. *Semiconductor devices for power converters of electromechanical systems of electric vehicles.*
14. *Explain with examples in which mechanisms it is necessary to use systems of frequency, vector sensorless, and vector sensor control.*
15. *Basic information about photo-pulse speed sensors.*
16. *The main ways of transmitting signals from photo pulse speed sensors.*
17. *Signal processing from photo-pulse speed sensors at the hardware level.*
18. *Signal processing from photo-pulse speed sensors at the software level.*
19. *Basic information about current sensors.*
20. *The principle of operation of current sensors using PWM.*
21. *Current sensors based on optocoupled ADC-DAC.*
22. *Explain the principle of operation of current and voltage sensors on the Hall effect.*
23. *Air conditioning signals from current sensors.*
24. *Software signal processing from current sensors.*
25. *Basic information about voltage sensors.*
26. *Air conditioning signals from DC and AC sensors.*
27. *Options for constructing the charging circuit of the filter capacity of the DC link filter.*
28. *Choice of charging relay and resistor.*
29. *Calculation of the filter capacity of the DC link.*
30. *Calculation of the braking resistor.*
31. *Justify in which cases it is necessary to install a braking resistor.*
32. *Calculation of the clamp key.*
33. *Calculation and selection of input rectifier.*
34. *Purpose of the radio frequency filter.*
35. *Purpose of the output filter of frequency converters.*
36. *Explain the purpose of the charging circuit of the DC link filter capacity.*
37. *Calculation and selection of power inverter switches.*
38. *Explain what an "intelligent power module" is.*

39. *Explain the advantages and disadvantages of power schemes, which are built on discrete elements and using "intelligent modules".*
40. *Explain the purpose of drivers.*
41. *Basic protection schemes of inverters.*
42. *Explain the principle of operation of drivers with voltage bias.*
43. *The use of optocouplers in the circuits of the control pulses of the inverter keys.*
44. *Explain the principle of operation of switching power supplies.*
45. *Explain the need to connect the power supply input of the converter control system to the DC link.*
46. *What functions are assigned to the control controller of the frequency converter?*
47. *Explain why digital signal processors are mainly used in modern electric drives.*
48. *Functional diagram of a typical control controller.*
49. *Describe the minimum set of signals required to control the frequency converter.*
50. *Features of designing microprocessor control systems for electric drives.*
51. *Separation of analog and digital signals.*
52. *Separation of low-current and power circuits.*
53. *Organization of discrete output circuits.*
54. *Organization of discrete input circuits.*
55. *Analog inputs of frequency converters.*
56. *Implementation of analog output of the frequency converter.*
57. *Organization of RS-485 communication interface*
58. *Organization of CAN communication interface*
59. *Controller power supply organization.*
60. *Features of application of linear and pulse regulators.*
61. *Features of application of DC-DC converters.*
62. *Protection of converters and motors against overheating.*
63. *External connections of converters.*
64. *Features of converter design for vector control systems.*
65. *Selection of drivers for IGBT power switches.*
66. *Explain the purpose of blocking capacitors at the power pins of chips.*
67. *Explain the need to separate digital and analog "ground"*
68. *Explain the need for galvanic isolation between power and control parts.*
69. *Semiconductor losses and converter cooling.*

***Certificates of distance or online courses on the subject can be credited subject to compliance with the requirements set out in Order № 7-177 of 01.10.2020 On approval of the provisions on recognition in the KPI. Igor Sikorsky learning outcomes acquired in non-formal / informal education***

**Work program of the discipline (syllabus):**

**Folded**Associate Professor of Automation of Electromechanical Systems and Electric Drive FEA, Dr. Serhii Kovbasa.

**Approved**Department of Automation of Electromechanical Systems and Electric Drive FEA (protocol № 12 dated 30.06.2021)

**Agreed** Methodical commission of the faculty[1] (Minutes № __ of _____)

[1]Methodical council of the university - for general university disciplines.