Universitatea Națională de Știință și Tehnologie Politehnica București
Facultatea de Electronică, Telecomunicații și
Tehnologia Informației

COURSE DESCRIPTION

1. Program identification information

1.1 Higher education institution	**National University of Science and Technology Politehnica Bucharest**
1.2 Faculty	**Electronics, Telecommunications and Information Technology**
1.3 Department	**Telecommunications**
1.4 Domain of studies	Electronic Engineering, Telecommunications and Information Technology
1.5 Cycle of studies	Masters
1.6 Programme of studies	Electric Vehicle Propulsion and Control

2. Date despre disciplină

2.1 Course name (ro) (en)				Cerințe specifice stocării energiei Energy Storage Requirements			
2.2 Course Lecturer				Conf. Dr. Lucian Andrei PERIȘOARĂ			
2.3 Instructor for practical activities				Conf. Dr. Lucian Andrei PERIȘOARĂ			
2.4 Year of studies	2	2.5 Semester	I	2.6. Evaluation type	E	2.7 Course regime	Ob
2.8 Course type		DA	2.9 Course code	UPB.04.M3.O.24-22		2.10 Tipul de notare	Nota

3. Total estimated time (hours per semester for academic activities)

3.1 Number of hours per week	3	Out of which: 3.2 course	2.00	3.3 seminary/laboratory	1
3.4 Total hours in the curricula	42.00	Out of which: 3.5 course	28	3.6 seminary/laboratory	14
Distribution of time:					hours
Study according to the manual, course support, bibliography and hand notes Supplemental documentation (library, electronic access resources, in the field, etc) Preparation for practical activities, homework, essays, portfolios, etc.					56
Tutoring					0
Examinations					2
Other activities (if any):					0

3.7 Total hours of individual study	58.00
3.8 Total hours per semester	100
3.9 Number of ECTS credit points	4

4. Prerequisites (if applicable) (where applicable)

4.1 Curriculum	Electronic Devices, Electronic Circuits, Digital Integrated Circuits, Microcontrollers, Industrial Electronics and Informatics, Power Electronics, Fundamentals of Electric Vehicles

4.2 Results of learning	General knowledge on energy storage devices, batteries, and ultracapacitors, and measurement techniques for testing.

5. Necessary conditions for the optimal development of teaching activities (where applicable)

5.1 Course	The lectures will be taken in a classroom with video projector and computer.
5.2 Seminary/ Laboratory/Project	Practical activities will be taken in a specialized laboratory, which will contain: different energy storage devices (Lead-Acid, LiFePO4 and Li-Ion batterries, ultracapacitors, large battery packs), electronic loads, testing platforms for energy storage, dedicated chargers for Lead-Acid and Li-Ion batteries, dedicated test and measurement equipments.

6. General objective *(Reffering to the teachers' intentions for students and to what the students will be thought during the course. It offers an idea on the position of course in the scientific domain, as well as the role it has for the study programme. The course topics, the justification of including the course in the currcula of the study programme, etc. will be described in a general manner)*

The course objectives are presentation of different types of energy storage techniques and devices: mechanical, electrochemical and electric, summarizing their features in terms of performance, cost, service life, management, charging facilities, and safety.
But in our days, every electric mean of transportation (hoovers, bicycles, scooters, forklifts, cars, buses) is powered by a lithium-ion battery. This course presents the state-of-the-art in research and development of battery technologies used in Electric Vehicles (EV) or Energy Storage Systems (ESS). Different battery chemistries are considered: Lead-Acid, NiMH, Li-Ion, LiFePO4, NMC. For modeling and simulation, the Electrochemical model (EC) and Electrochemical-thermal model (ECT) are considered. Performance parameters used for energy storage evaluation are State of charge (SOC), State of health (SOH), Beginning of life (BOL), End of life (EOL), different measurement techniques and estimation / prediction algorithms being analyzed and compared.

7. Competences *(Proven capacity to use knowledge, aptitudes and personal, social and/or methodological abilities in work or study situations and for personal and proffesional growth. They refflect the empolyers requirements.)*

Specific Competences	- To apply fundamental and specialized knowledge to solve complex problems which are specific to Energy Storage Devices, Rechargeable batteries, and supercapacitors; - To develop engineering solutions for solving technological problems in the fields of renewable energy systems; - To apply the knowledge from the field of Applied Electronics in order to evaluate the performance of batteries and supercapacitors during their charging or discharging;
Transversal (General) Competences	- Responsibly working in a multidisciplinary team with abilities to assume roles specific to different hierarchical levels; - Capacity to identify the need for continuous education and efficient use of information sources, communication resources and training assistance (Internet portals, specialized software, databases, online courses) both in Romanian and a foreign language.

8. Learning outcomes *(Synthetic descriptions for what a student will be capable of doing or showing at the completion of a course. The learning outcomes reflect the student's acomplishments and to a lesser extent the teachers' intentions. The learning outcomes inform the students of what is expected from them with respect to performance and to obtain the desired grades and ECTS points. They are defined in concise terms, using verbs similar to the examples below and indicate what will be required for evaluation. The learning outcomes will be formulated so that the correlation with the competences defined in section 7 is highlighted.)*

Knowledge	*The result of knowledge aquisition through learning. The knowledge represents the totality of facts, priciples, theories and practices for a given work or study field. They can be theoretical and/or factual.* - understanding manufacturing processes and technologies for electrochemical storage devices; - design of particular battery packs depending on the user requirements; - understanding and application of safety rules in manufacturing and maintenance of battery packs.
Skills	*The capacity to apply the knowledge and use the know-how for completing tasks and solving problems. The skills are described as being cognitive (requiring the use of logical, intuitive and creative thinking) or practical (implying manual dexterity and the use of methods, materials, tools and intrumentation).* - installation and configuration of large battery packs for Electric Vehicles; - installation and configuration of battery management systems on large battery packs; - testing the performance of different energy storage devices, batteries and supercapacitors; - creation of business models and developing new strategies in the field of energy storage; - assessing policy plans and regulations for batteries recycling;
Responsability and autonomy	*The student's capacity to autonomously and responsably apply their knowledge and skills.* - Selection and analyzing of appropriate bibliographic sources. - Respect the principles of academic ethics, correctly citing the bibliographic sources used. - Demonstrates collaboration with other colleagues and teaching staff - Promotes/contributes through new solutions related to the specialized field to improve the quality of social life. - Identifies sustainable solutions to solve problems in social and economic life. - Apply principles of professional ethics/deontology in the analysis of the impact of electric vehicle technologies on the environment. - Analyze and capitalize on business opportunities in the field of electric vehicles.

9. Teaching techniques *(Student centric techniques will be considered. The means for students to participate in defining their own study path, the identification of eventual fallbacks and the remedial measures that will be adopted in those cases will be described.)*

For lectures, teaching is carried out through the presentation and questioning methods. Modern teaching methods (video projector) are used for presentation of the course notes, applications notes, videos and demonstrative software applications. The lectures notes and presentations are available to students in pdf format on Moodle platform.

For practical applications, teaching is based on experimentation, combining mathematical modelling with experimental simulation using special development software (Matlab, PSIM, Orcad). Also, to verify the theoretical models, practical measurement will be made on different testing platforms using dedicated test and measurement equipments..

10. Contents

COURSE

Chapter	Content	No. hours
1	Introduction to Energy Storage Systems (ESS). The need for energy storage. History and evolution. Applications. Energy storage methods.	2
2	Mechanical energy storage: pumped hydro, compressed air, flywheel. Advantages and disadvantages.	2
3	Chemical and electrochemical storage of energy. Single use batteries (Zinc, Alkaline). Rechargeable batteries (Ni-Cd, Ni-MH, Lead-Acid, LiFePO4, NMC, LCO, etc.).	8
4	Electrical and electromagnetic storage of energy. Supercapacitors and inductors.	4
5	Hydrogen Fuel Cells for Electric Vehicles.	2
6	Battery modelling for simulation. Electrochemical (EC) model. Electrochemical-Thermal (ECT) model.	2
7	Battery charging methods. Constant Voltage (CV), Constant Current (CC) and Hybrid methods. Charging optimization methods: multistage charging, pulse charging.	2
8	Battery testing. Measurement techniques and estimation algorithms of performance parameters: State-of-Charge (SOC), State-of-Health (SOH), Beginning-of-Life (BOL), End-of-Life (EOL).	2
9	Requirements for sizing battery cells and battery packs.	2
10	Battery recycling methods and policies.	2
	Total:	28

Bibliography:

[Hug08] Robert Huggins, *Advanced Batteries: Materials Science Aspects*, Springer Science & Business Media, 2008.
[Hug10] Robert Huggins, *Energy Storage*, Springer Science & Business Media, 2010.
[Bru13] Yves Brunet, *Energy Storage*, John Wiley & Sons, 2013.
[ZL19] Thomas Zell, Robert Langer, *Hydrogen Storage*, Walter de Gruyter GmbH & Co KG, 2019
[Sor05] Bent Sørensen, *Hydrogen and Fuel Cells: Emerging Technologies and Applications*, Academic Press, 2005.
[KK12] Birol Kilkis, Sadik Kakaç, *Energy Storage Systems*, Springer Science & Business Media, 2012.
[CKA07] Z. Chlodnicki, W. Koczara, N. Al-Khayat, "*Hybrid UPC Based on Supercapacitor Energy Storage and Adjustable Speed Generator*", 2007.
[EGG05] M. Ehsani, Y. Gao, S. E. Gay, A. Emadi, "Modern Electric, Hybrid Electric, and Fuel Cell Vehicles - Fundamentals, Theory, and Design", CRC Press, 2005.
[PBD08] V. Pop, H. J. Bergveld, D. Danilov, P. P. L. Regtien, P. H.L. Notten, "Battery Management Systems - Accurate State-of-Charge Indication for Battery-Powered Applications", Springer, 2008.
[And10] D. Andrea, "Battery management systems for large lithium-ion battery packs", Artech House, 2010.
[BQ13] Y. Barsukov, J. Qian, "Battery power management for portable devices", Artech House, 2013
[PL18] G. Pistoia, B. Liaw, "Behaviour of Lithium-Ion Batteries in Electric Vehicles: Battery Health, Performance, Safety, and Cost", Springer, 2018.
[HTR18] K. S. Hariharan, P. Tagade, S. Ramachandran, "Mathematical Modeling of Lithium Batteries From Electrochemical Models to State Estimator Algorithms", Springer, 2018.

LABORATORY

Crt. no.	Content	No. hours
1	Measurement of the internal resistance of an energy storage device.	2

2	Measurement of the capacity of an energy storage device.	2
3	Performance testing of Lead-Acid batteries.	2
4	Performance testing of LiFePO4 batteries.	2
5	Performance testing of Supercapacitors.	2
6	Performance testing of hybrid systems, Batteries-Supercapacitors.	2
7	Evaluation	2
	Total:	14

Bibliography:

1. V. Pop, H. J. Bergveld, D. Danilov, P. P. L. Regtien, P. H.L. Notten, "Battery Management Systems - Accurate State-of-Charge Indication for Battery-Powered Applications", Springer, 2008.
2. Y. Barsukov, J. Qian, "Battery power management for portable devices", Artech House, 2013
3. G. Pistoia, B. Liaw, "Behaviour of Lithium-Ion Batteries in Electric Vehicles: Battery Health, Performance, Safety, and Cost", Springer, 2018.
4. K. S. Hariharan, P. Tagade, S. Ramachandran, "Mathematical Modeling of Lithium Batteries From Electrochemical Models to State Estimator Algorithms", Springer, 2018.
5. Ewert Energy Systems, "Orion BMS Wiring & Installation Manual", Rev. 4.1.
6. L. A. Perișoară, I. C. Guran, D. C. Costache, „A Passive Battery Management System for Fast Balancing of Four LiFePO4 Cells", 24th International Symposium for Design and Technology in Electronic Packaging (SIITME 2018), Iași, Romania, Oct. 25-28, 2018.
7. B. Anton, A. Florescu, L. A. Perișoară, A. Vasile, R. C. Constantinescu, Ș. G. Roșu, „Methods of Maximizing Power Efficiency for Hybrid Vehicles", Revue Roumaine des Sciences Techniques – Serie Électrotechnique et Énergétique, Vol. 64, Issue 1, pp. 57–62, Jan.-Mar. 2019.
8. L. A. Perișoară, D. C. Costache, I. C. Guran, Ș. G. Roșu, A. Florescu, „Active Balancing for Efficient Management of a 4S1P LiFePO4 Battery Pack", in Proc. of the 11th International Symposium on Advanced Topics in Electrical Engineering (ATEE 2019), Bucharest, Romania, March 28-30, 2019.
9. Ș. G. Roșu, M. Ș. Teodorescu, A. Florescu, L. A. Perișoară, "Study of Operating Conditions Impact on Wireless Power Transfer Systems Performance", in Proc. of the 11th International Symposium on Advanced Topics in Electrical Engineering (ATEE 2019), Bucharest, Romania, March 28-30, 2019.

11. Evaluation

Activity type	11.1 Evaluation criteria	11.2 Evaluation methods	11.3 Percentage of final grade
11.4 Course	- knowledge and understanding of fundamental theoretical notions; - comparative analysis of energy storage methods and devices; - capacity to apply the theoretical notions to solve practical problems.	Final examination consists of a quiz test which covers all lectures and contains 20 questions.	60%

11.5 Seminary/laboratory/project	- design and simulation of a battery cell for battery packs; - analysis of the simulation results. - using measurement equipments for battery testing; - analysis of the measured results.	Final examination consists of a quiz test with 20 questions from laboratory platforms.	40%
11.6 Passing conditions			
Accumulating at least 50 points out of 100 points.			

12. Corroborate the content of the course with the expectations of representatives of employers and representative professional associations in the field of the program, as well as with the current state of knowledge in the scientific field approached and practices in higher education institutions in the European Higher Education Area (EHEA)

Taking into account the interdisciplinary nature of energy storage systems, this course prepares graduates for product design, development, manufacturing and testing in different engineering areas: automotive, energy storage systems, renewable energy, smart grids, energy policy.

The lectures present a systematic and detailed description of theory and design of energy storage devices, with the emphasis on different storage devices: electrochemical (lithium batteries), electrical (ultracapacitors).

The practical activities provide a hands-on look for the modeling of battery cells and the design, simulation, installation, exploitation and maintenance of battery pack.

The master program provides to graduate students appropriate skills and training for the actual needs and scientific and technological qualifications, of high quality and competitively, allowing them rapid employment after graduation. This fact is consistent with the university policies, both in terms of content and structure, but also in terms of skills and international openness offered to students.

Date	Course lecturer	Instructor(s) for practical activities
10.10.2024	Conf. Dr. Lucian Andrei PERIȘOARĂ	Conf. Dr. Lucian Andrei PERIȘOARĂ

Date of department approval	Head of department
27.10.2024	Conf. Dr. Serban Georgica Obreja

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Date of approval in the Faculty Council	Dean
25.10.2024	Prof. Dr. Mihnea Udrea