

ELEKTROMOBILNOST

UČNI NAČRT PREDMETA/COURSE SYLLABUS

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| Predmet: | Elektromobilnost |
| Course title: | Electromobility |
| Članica nosilka/UL Member: | UL FS |

| Študijski programi in stopnja | Študijska smer | Letnik | Semestri | Izbirnost |
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| Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski (od študijskega leta 2024/2025 dalje) | Energetsko strojništvo (smer) | 2. letnik | 1. semester | obvezni |

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| Univerzitetna koda predmeta/University course code: | 0566863 |
| Koda učne enote na članici/UL Member course code: | 6008-M |

| Predavanja /Lectures | Seminar /Seminar | Vaje /Tutorials | Klinične vaje /Clinical tutorials | Druge oblike študija /Other forms of study | Samostojno delo /Individual student work | ECTS |
|-------------------------|---------------------|--------------------|--------------------------------------|---|---|------|
| 30 | | 30 | | | 65 | 5 |

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| Nosilec predmeta/Lecturer: | Klemen Zelič, Tomaž Katrašnik |
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| Izvajalci predavanj: | |
| Izvajalci seminarjev: | |
| Izvajalci vaj: | |
| Izvajalci kliničnih vaj: | |
| Izvajalci drugih oblik: | |
| Izvajalci praktičnega usposabljanja: | |

Vrsta predmeta/Course type:

Obvezni strokovni predmet na smeri Energetsko strojništvo, ki je izbirni strokovni predmet na ostalih smereh./Compulsory specialised course in the study of Energy engineering, which is an elective specialised course in other fields of study.

Jeziki/Languages:

Predavanja/Lectures:

Slovenščina

Vaje/Tutorial:

Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:**Prerequisites:**

Izpolnjevanje pogojev za vpis v Magistrski študijski program II. stopnje Strojništvo - Razvojno raziskovalni program.

Meeting the enrollment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.

Vsebina:**Content (Syllabus outline):**

1. predavanje:

- Primeri elektrificiranih pogonov (hibridni, priključni hibridni, baterijski električni, hibridni z gorivnimi celicami) v prometu in identifikacija ter sistemizacija komponent pogonov
- Umestitev elektromobilnosti v različne poti konverzije energijskih vektorjev

2. predavanje:

- Raba energije in neposredni ter posredni izpusti onesnažil pogonov z ozirom na življenjski cikel vozila, konverzijo od vira do koles in konverzijo od rezervoarja za energijo do koles
- Tehnološke smernice in zahteve razvoja elektrificiranih pogonov

3. predavanje: Baterije 1:

- Izvedbe baterij, sestavni deli in osnovni transportni ter elektrokemični procesi
- Inercijske baterije (poudarek na litijevih tehnologijah): zasnova,

1. Lecture:

- Examples of electrified powertrains (hybrid, plug-in hybrids, battery electric, fuel cell hybrid powertrains) in mobile applications and identification and classification of their components,
- Positioning of electromobility in various conversion paths of energy vectors.

2. Lecture:

- Use of energy and direct and indirect emissions of vehicle's powertrains with respect to life cycle of the vehicle, conversion from Well-to-Wheel and conversion from Tank-to-Wheel,
- Technology guidelines and R&D requirements of electrified powertrains.

3. Lecture: Batteries 1:

- Types of batteries, constitutive parts and basic transport and electrochemical processes,

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| <p>procesi in zmogljivosti insercijskih baterij</p> <p>4. predavanje: Baterije 2:</p> <ul style="list-style-type: none"> • Degradacijski procesi v baterijah: identifikacija procesov, osnovni mehanizmi, interakcije mehanizmov in vplivni parametri • Vpliv degradacijskih procesov na varnost baterij • Napredne baterijske tehnologije: pregled tehnologij s kovinsko elektrodo in trdnim elektrolitom ter natrijevih, litij žveplo in drugih naprednih tehnologij <p>5. predavanje: Baterije 3:</p> <ul style="list-style-type: none"> • Protokoli polnjenja in praznjenja baterij ter povezava z izvedbami in zasnovami baterij • Vpliv načina polnjenja in praznjenja na generacijo toplote in izkoristek baterije • Termoregulacija baterij • Hitro polnjenje baterij: zahteve in omejitve • Diagnostika <p>6. predavanje: Gorivne celice 1:</p> <ul style="list-style-type: none"> • Izvedbe gorivnih celic, sestavni deli in osnovni transportni ter elektrokemični procesi • Gorivne celice s protonskimi izmenjalnimi membranami: zasnova, procesi in zmogljivosti <p>7. predavanje: Gorivne celice 2:</p> <ul style="list-style-type: none"> • Degradacijski procesi v gorivnih celicah: identifikacija procesov, osnovni mehanizmi, interakcije mehanizmov in vplivni parametri • Vpliv degradacijskih procesov na varnost gorivnih celic • Termoregulacija gorivnih celic • Druge tehnologije gorivnih celic: poudarek na gorivnih celicah s trdnimi oksidi • Diagnostika <p>8. predavanje:</p> <ul style="list-style-type: none"> • Ultrakondenzatorji: sestavni deli in osnovni transportni ter | <ul style="list-style-type: none"> • Insertion batteries (emphasis on Li-ion technologies): design, processes and performances of insertion batteries. <p>4. Lecture: Batteries 2:</p> <ul style="list-style-type: none"> • Degradation processes in batteries: identification of underlying process, basic mechanisms, interaction between mechanisms and influential parameters, • Influence of degradation processes on battery safety, • Advanced battery technologies: overview of metal electrode and solid electrolyte as well as sodium, lithium sulphur and other advanced technologies. <p>5. Lecture: Batteries 3:</p> <ul style="list-style-type: none"> • Charging and discharging protocols and interrelation to battery types and designs, • Impact of charging and discharging protocol on heat generation and efficiency of batteries • Thermoregulation of batteries, • Fast charging: requirements and limitations, • Diagnostics. <p>6. Lecture: Fuel cells 1:</p> <ul style="list-style-type: none"> • Types of fuel cells, constitutive parts and basic transport and electrochemical processes, • Proton exchange membrane fuel cells: design, processes and performances. <p>7. Lecture: Fuel cells 2:</p> <ul style="list-style-type: none"> • Degradation processes in fuel cells: identification of underlying processes, basic mechanisms, interaction between mechanisms and influential parameters, • Influence of degradation processes on fuel cell safety, • Thermoregulation of fuel cells, • Other fuel cell technologies: emphasis on solid oxide fuel cells, • Diagnostics. |
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| <p>elektrokemični procesi</p> <ul style="list-style-type: none"> Kombinacije različnih elektrokemičnih naprav za optimizacijo gostote moči, gostote energije, življenjske dobe in cene <p>9. predavanje: Električni stroji:</p> <ul style="list-style-type: none"> Osnove elektromagnetizma v električnih strojih Izvedbe električnih strojev Prednosti in pomanjkljivosti določenih izvedb električnih strojev Inverterji in osnove krmiljenja električnih strojev Termoregulacija električnih strojev Diagnostika <p>10. predavanje:</p> <ul style="list-style-type: none"> Modeliranje komponent elektrificiranih pogonskih sistemov vozil: baterij, gorivnih celic, električnih strojev <p>11. predavanje:</p> <ul style="list-style-type: none"> Analiza topologij elektrificiranih pogonov vozil (hibridni, priključni hibridni, baterijski električni, hibridni z gorivnimi celicami) Značilnosti in zmogljivosti različnih topologij elektrificiranih pogonov vozil Energijski tokovi v elektrificiranih pogonih vozil <p>12. predavanje: Hibridni in priključni hibridni pogoni:</p> <ul style="list-style-type: none"> Izzivi in primeri uspešnih integracij električnih pogonov in motorja z notranjim zgorevanjem Optimiranje porabe energije in izpustov onesnažil z ozirom na namen uporabe, topologijo pogona in značilnosti ter zmogljivosti komponent <p>13. predavanje:</p> <ul style="list-style-type: none"> Optimiranje in sistemsko modeliranje elektrificiranih pogonskih sistemov vozil: izbira ustreznih komponent, njihovih moči oz. energij z ozirom na lastnosti vozila in namen uporabe <p>14. predavanje: Termoregulacija</p> | <p>8. Lecture:</p> <ul style="list-style-type: none"> Ultracapacitors: constitutive parts and basic transport and electrochemical processes. Combination of various electrochemical devices to optimize power density, energy density, lifetime and costs. <p>9. Lecture: Electric machines:</p> <ul style="list-style-type: none"> Basic electromagnetics in electric machines, Classification and design of electrical machines, Advantages and disadvantages of different types of electric machines, Inverters and control basics of electric machines, Thermoregulation of electric machines, Diagnostics. <p>10. Lecture:</p> <ul style="list-style-type: none"> Modelling of components of electrified powertrains: batteries, fuel cells, electric machines. <p>11. Lecture:</p> <ul style="list-style-type: none"> Analysis of topologies of electrified powertrains (hybrid, plug-in hybrids, battery electric, fuel cell hybrid powertrains), Performance and characteristics of different topologies of electrified powertrains, Energy flows in electrified powertrains. <p>12. Lecture: Hybrid and plug-in hybrid powertrains:</p> <ul style="list-style-type: none"> Challenges and examples of successful integration of electric drives and internal combustion engines, Optimisation of energy consumption and exhaust emissions with respect to the intended use of the vehicle, powertrain topology, and characteristics and performances of components. <p>13. Lecture:</p> |
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| <p>elektrificiranih pogonov vozil:</p> <ul style="list-style-type: none"> • izbira ustreznih topologij hladilnih sistemov, • izbira ustreznih hladilnih izvedb komponent • minimiranje porabe energije za termoregulacijo pogonskega sistema in potniškega prostora oz. porabe toplote v drugih delih vozila <p>15. predavanje:</p> <ul style="list-style-type: none"> • Refleksija in povezovanje vsebin • Učinkovitost energijskih pretvorb v različnih elektrificiranih pogonih vozil z ozirom na tip vozila in način uporabe – analiza primerov dobrih praks • Viharjenje na temo učinkovitejših pogonskih sistemov prihodnosti | <ul style="list-style-type: none"> • Optimisation and system level modelling of electrified powertrains: selection of adequate components, their power and energy outputs with respect to the intended use of the vehicle. <p>14. Lecture: Thermoregulation of electrified powertrains:</p> <ul style="list-style-type: none"> • Selection of adequate topologies of cooling systems, • Selection of adequate cooling designs of components, • Minimisation of energy consumption for powering thermoregulation system of the powertrain and of the cabin compartment or use of heat or cold in other parts of the vehicle. <p>15. Lecture:</p> <ul style="list-style-type: none"> • Reflection and integration of content, • Energy conversion efficiency of different electrified vehicle's powertrains with respect to the vehicle type and intended use of the vehicle – analysis of good practices, • Brainstorming on the subject of more efficient propulsion systems of the future. |
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Temeljna literatura in viri/Readings:

1. R O'hayre, SW Cha, W Colella, FB Prinz: Fuel cell fundamentals. John Wiley & Sons, 2016, [COBISS.SI-ID [15504667](#)]
2. Mench, M.M. Fuel cell engines. Wiley, 2008, [COBISS.SI-ID [23203111](#)]
3. Guzzella L, Sciarretta A.: Vehicle Propulsion Systems - Introduction to Modeling and Optimization, 2nd ed., Springer, 2007, ISBN 978-3-540-74691-1, [COBISS.SI-ID [11212571](#)]

Cilji in kompetence:

Cilji:

1. Razumeti teoretične osnove na področju elektromobilnosti in elektrificiranih pogonskih sistemov vozil
2. Spoznati umestitev elektromobilnosti v različne poti konverzije energijskih vektorjev
3. Spoznati procese in dejavnike staranja v relevantnih komponentah

Objectives and competences:

Objectives:

1. Understand the theoretical foundations in the field of electromobility and electrified vehicle propulsion systems
2. To know to classify electromobility in various conversion paths of energy vectors
3. To know processes and stressors in relevant components of electrified

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| <p>elektrificiranih pogonskih sistemov vozil</p> <p>4. Spoznati interakcije in soodvisnosti različnih komponent elektrificiranih pogonskih sistemov vozil</p> <p>5. Razumeti pristope za modeliranje procesov na ravni komponent in na ravni elektrificiranega pogonskega sistema vozila</p> <p>6. Razumeti pristope in znati snovati učinkovitejše in okolju prijaznejše elektrificirane pogonske sisteme vozil z ozirom na namen uporabe</p> <p>Kompetence:</p> <p>1. Obvladovanje temeljnih teoretičnih in aplikativnih znanj na področju elektromobilnosti (P2-MAG, S2-MAG)</p> <p>2. Sposobnost razumevanja interakcije in soodvisnosti različnih komponent elektrificiranih pogonskih sistemov vozil (P2-MAG)</p> <p>3. Sposobnost fizikalnega, matematičnega in numeričnega modeliranja komponent in sistemov elektrificiranih pogonskih sistemov vozil (P4-MAG)</p> <p>4. Sposobnost kritične presoje in snovanja elektrificiranih pogonskih sistemov vozil z ozirom na namen uporabe, zmogljivosti in mejne vrednosti izpustov onesnažil (S8-MAG)</p> | <p>vehicle propulsion systems</p> <p>4. To know and to understand interactions in interdependencies of different components electrified vehicle propulsion systems</p> <p>5. Understand modelling approaches for simulating components and systems of electrified powertrains</p> <p>6. Understand development approaches and to know how to design more efficient and environmentally friendly electrified vehicle propulsion systems for the intended use of the vehicle</p> <p>Competencies:</p> <p>1. Using the fundamental theoretical and applied knowledge in the field of electromobility (P2-MAG, S2-MAG)</p> <p>2. Mastering understanding of interactions in interdependencies of different components in electrified vehicle propulsion systems (P2-MAG)</p> <p>3. The ability for physical, mathematical and numerical modelling of components and systems of electrified powertrains (P4-MAG)</p> <p>4. The ability to critically evaluate and design electrified powertrains with respect to the intended use, performances and limiting values of pollutant emissions (S8-MAG)</p> |
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Predvideni študijski rezultati:

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| <p>Znanja:</p> <p>Poglabljeno teoretično, metodološko in analitično znanje z elementi raziskovanja, ki je osnova za zalo zahtevno znanstveno in strokovno delo na področju razvoja, snovanja in diagnostike elektrificiranih pogonskih sistemov vozil.</p> <p>Spretnosti:</p> <p>S1.1 Sposobnost vrednotenja topologij in procesov elektrificiranih pogonskih sistemov vozil.</p> <p>S1.2 Samostojna uporaba pridobljenega</p> | <p>Knowledge:</p> <p>Z1: In-depth theoretical, methodological and analytical knowledge with elements of research, which is the basis for scientific and professional work in the development, design and diagnostics of electrified vehicle propulsion systems.</p> <p>Skills:</p> <p>S1.1: Ability to evaluate different topologies and processes in electrified vehicle propulsion systems.</p> <p>S1.2: Independent use of acquired knowledge in the analysis, design and</p> |
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| <p>znanja pri analizi, snovanju in diagnostiki elektrificiranih pogonskih sistemov vozil.</p> <p>S1.3 Sposobnost snovanja učinkovitejših in okolju prijaznejših elektrificiranih pogonskih sistemov vozil z minimalnimi negativnimi vplivi na okolje.</p> <p>S1.4 Sposobnost nadaljnjega, samostojnega študija.</p> | <p>diagnostics of electrified vehicle propulsion systems.</p> <p>S1.3: Ability to design environmentally friendly electrified vehicle propulsion systems with minimized negative environmental impact.</p> <p>S1.4: Ability of independent self-driven education and research.</p> |
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Metode poučevanja in učenja:

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| P1 Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov. |
| P2 Obravnava snovi po urejeni in vnaprej razloženi sistematiki. |
| P3 Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri. |
| P4 Laboratorijske vaje. |
| P5 Uporaba študijskega gradiva v obliki (e-verzija predstavitve predavanj). |
| P8 Izdelava in predstavitev aplikativnih seminarskih nalog |
| P10 Uporaba anket v realnem času |
| P14 Virtualni eksperimenti |
| P15 Uporaba video vsebin kot priprava na predavanja in vaje |

Learning and teaching methods:

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| P1: Classroom lectures with inclusion of solving selected typical and practical examples. |
| P2: Presenting of the learning content in an orderly and pre-interpreted systematics |
| P3: Tutorials where theoretical knowledge of lectures is supported by computational examples. |
| P4: Laboratory work. |
| P5: Use of study materials in format (e-version of lecture presentation). |
| P8: Design and presentation of applied seminar work |
| P10: Use of real-time surveys |
| P14: Virtual Experiments |
| P15: Using video content to prepare for lectures and exercises |

Načini ocenjevanja:

Delež/ Weight

Assessment:

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| Teoretične vsebine (predavanja) | 50,00 % | Theory (lectures) |
| Samostojno delo na vajah | 50,00 % | Practical coursework |

Ocenjevalna lestvica:

Grading system:

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| 5 - 10, pri čemer velja, da je pozitivna ocena od 6 - 10 | 5 - 10, a student passes the exam if he is graded from 6 to 10 |
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Reference nosilca/Lecturer's references:

Tomaž Kutrašnik:

1. **KATRAŠNIK, Tomaž**, MOŠKON, Jože, ZELIČ, Klemen, MELE, Igor, RUIZ-ZEPEDA, Francisco, GABERŠČEK, Miran. Entering voltage hysteresis in phase-separating materials : revealing the electrochemical signature of the intraparticle phase-separated state. *Advanced materials*. [Online ed.]. Aug. 2023, vol. 35, iss. 31, [article no.] 2210937, str. 1-18, ilustr. ISSN 1521-4095. [COBISS.SI-ID [151199235](#)]
2. ZELIČ, Klemen, MELE, Igor, BHOWMIK, Arghya, **KATRAŠNIK, Tomaž**. Phase separating electrode materials - chemical inductors?. *Energy storage materials*. Feb. 2023, vol. 56, str. 489-494, ilustr. ISSN 2405-8297. [COBISS.SI-ID [140743427](#)]
3. KRAVOS, Andraž, KREGAR, Ambrož, PENG, Željko, BARBIR, Frano, **KATRAŠNIK, Tomaž**. Real-time capable transient model of liquid water dynamics in proton exchange membrane fuel cells. *Journal of power sources*. Sep. 2022, vol. 541, str. 1-16, ilustr. ISSN 0378-775 [COBISS.SI-ID [110908675](#)]
4. ZELIČ, Klemen, **KATRAŠNIK, Tomaž**. Thermodynamically consistent derivation of chemical potential of a battery solid particle from the regular solution theory applied to LiFePO *Scientific reports*, ISSN 2045-2322, Feb. 2019, vol. 9, f. 1-13. [COBISS.SI-ID [16474651](#)]
5. RAŠIĆ, Davor, **KATRAŠNIK, Tomaž**. Multi-domain and multi-scale model of a fuel cell electric vehicle to predict the effect of the operating conditions and component sizing on fuel cell degradation. *Energy conversion and management*. [Print ed.]. Sep. 2022, vol. 268, str. 1-27, ilustr. ISSN 0196-8904. [COBISS.SI-ID [117952259](#)]

Klemen Zelič:

1. **ZELIČ, Klemen**, MELE, Igor, BHOWMIK, Arghya, KATRAŠNIK, Tomaž. Phase separating electrode materials - chemical inductors?. *Energy storage materials*. Feb. 2023, vol. 56, str. 489-494, ilustr. ISSN 2405-8297. <https://www.sciencedirect.com/science/article/pii/S2405829723000090>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=144241>, DOI: [10.1016/j.ensm.2023.01.008](https://doi.org/10.1016/j.ensm.2023.01.008). [COBISS.SI-ID [140743427](#)]
2. KATRAŠNIK, Tomaž, MOŠKON, Jože, **ZELIČ, Klemen**, MELE, Igor, RUIZ-ZEPEDA, Francisco, GABERŠČEK, Miran. Entering voltage hysteresis in phase-separating materials : revealing the electrochemical signature of the intraparticle phase-separated state. *Advanced materials*. [Online ed.]. Aug. 2023, vol. 35, iss. 31, [article no.] 2210937, str. 1-18, ilustr. ISSN 1521-4095. <https://onlinelibrary.wiley.com/doi/10.1002/adma.202210937>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=148258>, <https://dirros.openscience.si/IzpisGradiva.php?id=16910>, DOI: [10.1002/adma.202210937](https://doi.org/10.1002/adma.202210937). [COBISS.SI-ID [151199235](#)]
3. KREGAR, Ambrož, **ZELIČ, Klemen**, KRAVOS, Andraž, KATRAŠNIK, Tomaž. Educational scale-bridging approach towards modelling of electric potential, electrochemical reactions, and species transport in PEM fuel cell. *Catalysts*. [Online ed.]. Jul. 2023, vol. 13, iss. 7, [article no.] 1131, str. 1-31, ilustr. ISSN 2073-4344. <https://www.mdpi.com/2073-4344/13/7/1131>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=148317>, DOI: [10.3390/catal13071131](https://doi.org/10.3390/catal13071131). [COBISS.SI-ID [161059843](#)]
4. KATRAŠNIK, Tomaž, MELE, Igor, **ZELIČ, Klemen**. Multi-scale modelling of the thermal runaway in li-ion batteries. V: RISTIĆ, Alenka (ur.), STRITIĆ, Uroš (ur.). *Enerstock 2021 : 15th International Virtual Conference on Energy Storage* :

June 9-11, 2021, Ljubljana, Slovenia : book of abstracts. 15th International Virtual Conference on Energy Storage, June 9-11, 2021, Ljubljana, Slovenia. [Ljubljana]: National Institute of Chemistry, Department of Inorganic Chemistry and Technology; Faculty of Mechanical Engineering, 2021. Str. 271-272. ISBN 978-961-6104-49-4. <https://www.enerstock2021.org/>. [COBISS.SI-ID [82149635](#)]

5. **ZELIČ, Klemen**, KATRAŠNIK, Tomaž, GABERŠČEK, Miran. Derivation of transmission line model from the concentrated solution theory (CST) for porous electrodes. *Journal of the electrochemical society*. [Online ed.]. 2021, vol. 168, no. 7, str. [1-12], ilustr. ISSN 1945-7111.
<https://iopscience.iop.org/article/10.1149/1945-7111/ac1314>, DOI: [10.1149/1945-7111/ac1314](https://doi.org/10.1149/1945-7111/ac1314). [COBISS.SI-ID [70090755](#)]