

UČNI NAČRT PREDMETA/COURSE SYLLABUS

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

Študijski programi in stopnja	Študijska smer	Letnik	Semestri
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski	Energetsko strojništvo (smer)	2. letnik	1. semester

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

Predavanja	Seminar	Vaje	Klinične vaje	Druge oblike študija	Samostojno delo	ECTS
30		30			65	5

Nosilec predmeta/Lecturer:	Tomaž Kutrašnik
-----------------------------------	-----------------

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: <ul style="list-style-type: none"> 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 	1. Lecture: <ul style="list-style-type: none"> Examples of electrified powertrains (hybrid, plug-in hybrids, battery electric, fuel cell hybrid powertrains) in mobile applications and identification and classification of their

<p>konverzije energijskih vektorjev</p> <p>2. predavanje:</p> <ul style="list-style-type: none"> • 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 <p>3. predavanje: Baterije 1:</p> <ul style="list-style-type: none"> • Izvedbe baterij, sestavni deli in osnovni transportni ter elektrokemični procesi • Insercijske baterije (poudarek na litijevih tehnologijah): zasnova, procesi in zmogljivosti insercijskih baterij <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 elektrokemični procesi 	<p>components,</p> <ul style="list-style-type: none"> • Positioning of electromobility in various conversion paths of energy vectors. <p>2. Lecture:</p> <ul style="list-style-type: none"> • 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. <p>3. Lecture: Batteries 1:</p> <ul style="list-style-type: none"> • Types of batteries, constitutive parts and basic transport and electrochemical processes, • 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,
--	--

<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 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"> • Diagnostics. <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> <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.
--	--

Temeljna literatura in viri/Readings:

1. Reiner Korthauer: Lithium-Ion Batteries Basics and Applications-Springer Berlin Heidelberg, 2018
2. John Newman, Karen E. Thomas-Alyea: Electrochemical Systems, 3rd Edition, Wiley, 2004
3. R O'hayre, SW Cha, W Colella, FB Prinz: Fuel cell fundamentals. John Wiley & Sons, 2016
4. Mench, M.M. Fuel cell engines. Wiley, 2008
5. BARBIR, F: PEM fuel cells: theory and practice. London, Academic Press, 2013
6. Guzzella L, Sciarretta A.: Vehicle Propulsion Systems - Introduction to Modeling and Optimization, 2nd ed., Springer, 2007, ISBN 978-3-540-74691-1

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 elektrificiranih pogonskih sistemov vozil
4. Spoznati interakcije in soodvisnosti različnih komponent elektrificiranih pogonskih sistemov vozil
5. Razumeti pristope za modeliranje procesov na ravni komponent in na ravni elektrificiranega pogonskega sistema vozila
6. Razumeti pristope in znati snovati učinkovitejše in okolju prijaznejše elektrificirane pogonske sisteme vozil z ozirom na namen uporabe

Kompetence:

1. Obvladovanje temeljnih teoretičnih in aplikativnih znanj na področju elektromobilnosti (P2-MAG, S2-MAG)
2. Sposobnost razumevanja interakcije in soodvisnosti različnih komponent elektrificiranih pogonskih sistemov vozil (P2-MAG)
3. Sposobnost fizikalnega, matematičnega in numeričnega modeliranja komponent in sistemov elektrificiranih pogonskih sistemov vozil (P4-MAG)
4. Sposobnost kritične presoje in snovanja elektrificiranih pogonskih sistemov vozil z ozirom na namen uporabe, zmožljivosti in mejne vrednosti

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 vehicle propulsion systems
4. To know and to understand interactions in interdependencies of different components electrified vehicle propulsion systems
5. Understand modelling approaches for simulating components and systems of electrified powertrains
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

Competencies:

1. Using the fundamental theoretical and applied knowledge in the field of electromobility (P2-MAG, S2-MAG)
2. Mastering understanding of interactions in interdependencies of different components in electrified vehicle propulsion systems (P2-MAG)
3. The ability for physical, mathematical and numerical modelling of components and systems of electrified powertrains (P4-MAG)
4. The ability to critically evaluate and design electrified powertrains with respect to the intended

izpustov onesnažil (S8-MAG)	use, performances and limiting values of pollutant emissions (S8-MAG)
-----------------------------	---

Predvideni študijski rezultati:

<p>Znanja:</p> <p>Poglobljeno 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 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 nadaljnega, samostojnega študija.</p>
--

Intended learning outcomes:

<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 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>
--

Metode poučevanja in učenja:

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

Learning and teaching methods:

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

Načini ocenjevanja:

Delež/Weight

Assessment:

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

--	--	--

Reference nosilca/Lecturer's references:

Tomaž Katrašnik

1. ZELIČ, Klemen, **KATRAŠNIK, Tomaž**. Thermodynamically consistent and computationally efficient 0D lithium intercalation model of a phase separating cathode particle. *Journal of the Electrochemical Society*, ISSN 1945-7111. [Online ed.], 2019, vol. 166, iss. 14, f. A3242-A3249
2. ZELIČ, Klemen, **KATRAŠNIK, Tomaž**. Thermodynamically consistent derivation of chemical potential of a battery solid particle from the regular solution theory applied to LiFePO₄. *Scientific reports*, ISSN 2045-2322, Feb. 2019, vol. 9, f. 1-13
3. SENEGAČNIK, Jure, TAVČAR, Gregor, **KATRAŠNIK, Tomaž**. Computationally efficient approach for solving time dependent diffusion equation with discrete temporal convolution applied to granular particles of battery electrodes. *Journal of power sources*, ISSN 0378-7753, Mar. 2015, vol. 278, str. 760-772
4. TAVČAR, Gregor, **KATRAŠNIK, Tomaž**. An innovative hybrid 3D analytic-numerical approach for system level modelling of PEM fuel cells. *Energies*, ISSN 1996-1073, Oct. 2013, vol. 6, iss. 10, str. 5426-5485
5. TAVČAR, Gregor, **KATRAŠNIK, Tomaž**. A computationally efficient hybrid 3D analytic-numerical approach for modelling species transport in a proton exchange membrane fuel cell. *Journal of power sources*, ISSN 0378-7753, Avg. 2013, ilustr., vol. 236, str. 321-340