Tampere University

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Exam of the course *DEE-54206 Electrical Energy Storages and Electric Vehicles*, 5 cr.

Please answer **question 1 AND <u>six</u> questions from 2-8** (it means you <u>can and must</u> leave one question unanswered). **Note** that question 8 is more valuable in points! The use of calculator and lecture materials is allowed. Return the exam by 12:05 per email to joni.markkula@tuni.fi . If you have questions related to exam, use MS Teams direct messages.

Exam maximum points: 36 p *(Q1 max **10p**, Q2-Q7 max **4p** per question, Q8 max **6p**)*

You may answer in Finnish or English.

0. *Sign on first page: "I, [your name], assure that I have done this exam personally, without help from others. This exam paper represents my knowledge on the subject today."*

1. Answer TRUE or FALSE (+0.5 for correct, -0.5 for incorrect, 0 for empty, total max **10 p**)

1. Annual worldwide demand for crude oil has been increasing over the last years.
2. Considering the energy storages operating today in power system applications, most of the energy capacity is in lithium-ion battery energy storages.
3. Battery technology innovations generally enter the market in about 10 years
4. C-rate describes the battery maximum temperature rating
5. All lithium-ion battery chemistries have same voltage
6. Specific energy (in Wh/kg) of a typical lithium-ion battery cell is around 150–250 Wh/kg
7. Lithium-ion battery cell voltage is higher than lead-acid cell voltage
8. Active cell balancing is required in li-ion battery systems
9. In EV charging mode 4 is meant for public quick charging and mode 2 for temporary home charging
10. DC charging means that the AC-DC converter is in the vehicle
11. Inductive charging efficiency can exceed 90%
12. Flywheels are good for storing energy from days to weeks due to their high round trip efficiency
13. Power grid frequency starts to decrease when there is too much production in network
14. Unpredictable production will increase the need of flexible loads in the future
15. Smart charging based on price will always decrease also emissions
16. Global EV sales is almost 5 M vehicles per year which is ca. 6% of all new passenger vehicles sales
17. Consumer price-based charge optimization will be beneficial also for the distribution network
18. Passenger EV energy consumption is ca. 0.2 kWh/km
19. Standards between EV charging station operator and power system operator are not yet well defined
20. Energy consumption will increase significantly if we move globally to full electromobility

2. Lithium-ion batteries: Explain with illustration and in writing how charging and discharging lithium-ion battery works. (**4 p**)

3. Energy storages: How are the three heat energy storage methods different from each other?

4. Energy storage systems: Compare the energy efficiency and costs of power-to-gas versus direct electric in creating sustainable transportation system (**4 p**)

5. Energy storages: What factors would you take into account when evaluating environmental impact of energy storage? (4 p)

6. Electric vehicles: What has been the enabler of current wave of electric vehicles? What is still slowing down adoption of electromobility? (**4 p**)

7. Smart charging: Who are the actors that would benefit from smart charging and how? What would be their motive to advance smart charging vs. uncontrolled charging? (**4 p**)

8. Lifetime costs: Consider two electric buses that have different battery properties and thus different charging mechanisms. The first bus (A) is charged over the night at bus depot and it is on duty the whole day. Battery price is low and so is charging station. The second bus (B) is charged at route end stops on every full round and thus a smaller battery is required but also it needs to be able to take higher charging power. Battery and charging station are both expensive but the manufacturer assures that lifetime costs will be lower due to better battery. What is the **net present values** of the buses during their lifetimes? (**6 p**)

	A	B
Bus price	100 000 €	100 000 €
Battery size	200 kWh	40 kWh
Battery price (€/kWh)	350 €/kWh	2000 €/kWh
Charging station cost	60 000 €	150 000 €
Battery cycle life	1000	10 000
Bus energy consumption	1.2 kWh/km	1.0 kWh/km

Distance per year	60 000 km
Cost of electricity	0,15 €/kWh
Battery price yearly decrease	5%
Internal discount rate	10%
Bus lifetime	12 years

(Hint : discount coefficient is $\left(\frac{1}{\left(1+\frac{p\%}{100\%}\right)^{i}}\right)$ *)*

Kysymyksiä:

- How is supercapacitor different from “normal” electrolyte capacitor?
- What is *Safe Operating Area* in lithium-ion batteries? How does electronics help with guarding it?
- What factors would you take into account when evaluating environmental impact of energy storage?
- What are the types of heat energy storages and how do they differ from each other?
- Explain what is voltage curve in electrochemical energy storages.
- What is the difference between series and parallel hybrid
- Which one of two energy storages is a better investment from financial point of view … A or B
-

Pikkukysymyksiä:

- Pumped hydro presents over 95% of global energy storage power capacity
- Power grid frequency starts to decrease when there is too much production in network (F)
- Flywheel are good for days to weeks energy storing due to their high round trip efficiency (F)
- Lithium molecyles are the energy carrier …
- Super conducting mangnetic energy storage is good for long term storing as there are no losses in the super conductor (F, cannot be unplugged, always online)
- Primary batteries are meant for onetime use
- Flat voltage..
- Energy consumption will increase significantly if we move globally to full electromobility (F, decrease, electricity consumption will increase a little but not energy as whole ever)
- Mode 2 charging recommended for everyday charging of electric vehicles (F, Mode 3)
- Batteries can be charged with also AC current (F,
- Vehicle to grid causes battery extra wear making it financially not a good option (F, value is high, wear is modest)
- Distribution network companies wi
- Grid frequency is an indicator of power balance in electrical grid (T)
- Shifting
- Intermittent production will increase the need of flexible loads in the future (T)
- Compressed energy storage can be used for seasonal energy storages (T)
- Optimizing charging time will per price will be beneficial for the distribution network (T)
- Smart charging based on price will always decrease emissions also (F)
- DC motors are more common in modern electric vehicles than AC motors (F)
- Synthetic gases and liquids
- TRL
- Global EV sales is almost 5 M vehicles per year which is ca. 6% of all new passenger vehicles sales (T)
- Passenger EV energy consumption is ca. 0.2 kWh/km
- EV charging stations communicate with the vehicle before charging is started
- C

X. Lifetime costs (4 p.)

Consider replacing a city diesel bus with electric bus with following parameters:

	Diesel bus	Electric bus
Price	200 000 €	400 000 €
Energy consumption	30 l / 100 km	1.0 kWh/km
Energy cost	1.2 € / l (diesel)	0.10 €/kWh (electricity)
Driving distance per year	150 000 km	
Bus lifetime	12 years	

Additional eBus figures: high power charging station 300 k€, Battery replacement cost 60 000 €, battery size 50 kWh, battery cycle life 10 000 cycles

What is the total cost during the bus lifetime for both technologies? Calculate difference in net present value when interest rate is 7%. *(Hint : discount coefficient is* $\left(\frac{1}{\left(1+\frac{p\%}{100\%}\right)^{i}}\right)$ *)*

XX.

4. Electric vehicles (4 p.)

Explain differences of over-night charging and opportunity charging of electric buses. How does it also effect power grid infrastructure? (2 p.)

How could electric vehicle “regular” and smart charging affect emissions? Explain also what the triggers for smart charging could be and what is the potential benefit for EV drivers. (4 p.)

BMS

5. Why is battery management system (BMS) important with li-ion batteries? Describe the key functionalities of BMS. (2 p.)

XX: energy storages

Energy storages (4 p.)

Compare the qualities (e.g. energy density) of three different energy storage technologies and give examples where they are used. Be specific with numbers (4 p.)