ENERGY STORAGE (DL)

(22WSP638)

Semester 2 2023 In Person Examination

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

Answer **ALL THREE** questions.

All questions carry equal marks.

Any approved University calculator is permitted.

A range of formulae and tables likely to be of benefit in the solution of these questions are provided at the rear of the paper.

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1.

a) Describe the main components common to all grid connected energy storage systems. [6 marks]

b) Figure Q1 shows a picture of a battery connected to a constant power load. Calculate the Energy available when the load is 0.1W, 10W and 1000W. Explain why these are different with reference to a Ragone plot.

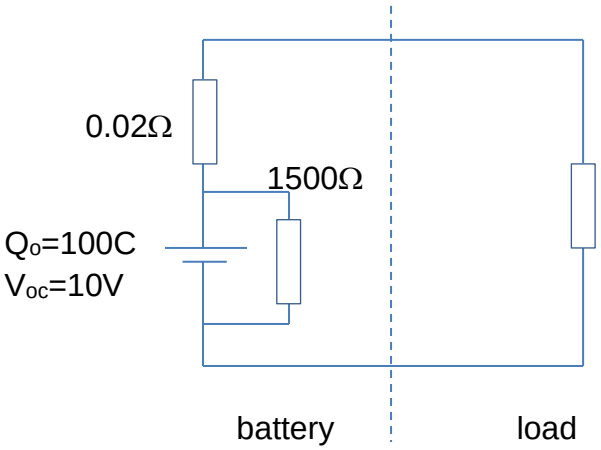

Figure Q1

[14 marks]

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2. This question relates to Compressed Air Energy Storage. You should assume that air is a perfect gas in all parts of this question with $c_p = 1.005\ \mathrm{kJkg^{-1}K^{-1}}$, $\gamma = 1.4$ and $R_{air} = 287\ \mathrm{Jkg^{-1}K^{-1}}$.

The following formula may be useful:

Work available adiabatic expansion: $W = mc_pT_1\left(1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right)$

Work available isothermal expansion: $W = mRT_1 \ln\left(\frac{P_1}{P_2}\right) = P_1V_1 \ln\left(\frac{P_1}{P_2}\right)$

a) Write down the ideal gas law. Define each of the terms and give units. [3 marks]

b) Proponents of CAES argue that it is a good option for energy storage where power is required for 6 hours or more and energy is to be stored for 6 hours – 2 weeks. Give **three** reasons why it may be a good option. [3 marks]

c) Explain the working differences between diabatic and adiabatic CAES. [3 marks]

d) A 500,000m^3 cavern is filled with air at 8 MPa and the ambient atmospheric pressure is 100 kPa. You may assume the temperature in the cavern is constant at 27^{o}C at all pressures. The minimum cavern pressure is 4 MPa. Calculate the theoretical energy available from the following, giving your answer in MWh:

i. The cavern is discharged from the maximum to the minimum pressure via one adiabatic expander. Air is throttled to 4MPa before entering the expander. [5 marks]

ii. The cavern is discharged from the maximum to the minimum pressure via one isothermal expander. Air is not throttled before entering the expander. Note the integral $\int_{p_1}^{p_2} \ln p\ dp = [p \ln p - p]_{p_1}^{p_2}$. [5 marks]

e) Comment on the outlet air temperature in (c) part (i) and its implications [1 mark]

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3.

a) Name two types of electrolyser for producing hydrogen from water, with one advantage and one disadvantage of each. [3 marks]

b) The following are components of an electrolyser system. What is the role of each? What might go wrong if each were missing:

i. Separator tanks

ii. Reverse osmosis unit

iii. De-oxo unit

iv. Dryer [4 marks]

c) A diesel-powered truck requires a peak mechanical power of 350 kW, an average power of 150kW. The truck will be re-designed to use a fuel cell running on hydrogen fuel and supplying power to the wheels via an electrical drive train.

i. When converted to hydrogen, the drive train will include a battery. What roles will this play and how will this benefit the the truck's performance? [1 mark]

ii. The efficiency of the fuel cell is 50% based on higher heating value. The efficiency of the drivetrain is 90%, and the truck is required to drive for up to 15 hours between refuelling. Assume that the average mechanical power requirement remains unchanged at 150kW. What mass of hydrogen will be used between refuelling? [2 marks]

iii. The hydrogen is to be stored onboard the truck as compressed gas at 350 bar pressure. The total mass of hydrogen is 10% greater than the usable mass because some 'cushion' gas remains in the tank to maintain pressure. The mass percentage of hydrogen is 8% of total full tank mass. What is the total weight of the hydrogen tank? What type of tank construction will provide the greatest hydrogen storage per mass of tank?

[3 marks]

iv. What is the internal volume of the hydrogen tank if the maximum working temperature is 100°C? The compressibility factor may be assumed to be equal to 1.1 at 350 bar. [3 marks]

v. List two other hydrogen storage technologies that might be used onboard a vehicle and why each is less suitable for this application. [2 marks]

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d) List 4 characteristics of hydrogen which are significantly different from those of other flammable gases from the point of view of safety.

[2 marks]

The following information and equations may be useful:

The higher heating value of hydrogen is 39.39 kWh/kg

PV=ZnRT

Temperature in kelvin = temperature in degrees Celsius + 273.15

The universal gas constant = 8.314 J mol^{-1} K^{-1}

The molecular mass of hydrogen is 2.016 g mol^{-1}

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