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The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2012-13 (2.0 hours)

EEE6021 Energy Utilisation 6

Answer **THREE** questions. **No marks will be awarded for solutions to a fourth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1. **a.** Describe, with the aid of an appropriate diagram, the basic principle of operation of an alkaline electrolyte fuel cell, and the key factors that may influence its reaction rate. **(6)**

b. In an ideal system, the change of molar specific Gibbs free energy of formation $\Delta\overline{g}_f$ of an alkaline hydrogen fuel cell is fully converted into electrical energy. Derive an expression for the reversible open-circuit voltage of the fuel cell. **(5)**

c. The changes of molar specific Gibbs free energy of formation, $\Delta\overline{g}_f$, for the basic hydrogen fuel cell reaction as a function of temperature under standard pressure 0.1 MPa (or 1 bar) are given in Table 1.

Table 1

Form of H_2O	Temperature ^0C	$\Delta\overline{g}_f$ (kJ/mole)
Liquid	25	-237.2
Liquid	80	-228.2
Gas	80	-226.1
Gas	100	-225.2
Gas	200	-220.4
Gas	400	-210.3
Gas	600	-199.6
Gas	800	-188.6
Gas	1000	-177.4

Faraday constant = 96485 (C), molar gas constant = 8.314 (J/K/mole).

(i) Explain the underlying cause of why $\Delta\overline{g}_f$ decreases with increase in temperature. **(2)**

(ii) If oxygen is supplied at a pressure of 2 bars from air with 20.95% oxygen concentration, and pure hydrogen is used at the same pressure, the reaction **(5)** produces water vapour at a pressure of 1.8 bars. Calculate the reversible open-circuit voltage of the fuel cell at 200 °C and the maximum theoretical efficiency, given the "high heating value" of hydrogen being 285.84 (kJ/mole).

(iii)If pure oxygen is supplied and other operating conditions are the same, calculate the change in reversible open-circuit voltage. **(2)**

2. **a.** Sketch the output voltage versus load current density characteristic of a hydrogen fuel cell operating at a temperature below 100 °C, and describe the main causes of the cell voltage reduction from its ideal value with increasing current density. **(10)**

b. Describe the charge double layer effect in a fuel cell, and explain how this effect can be represented in an equivalent electrical circuit. **(6)**

c. Figure 1 shows the schematic of a fuel cell powered drive train for electric vehicles. Explain why a DC/DC converter and energy storage devices, e.g., battery or super-capacitors are often required in such a system. **(4)**

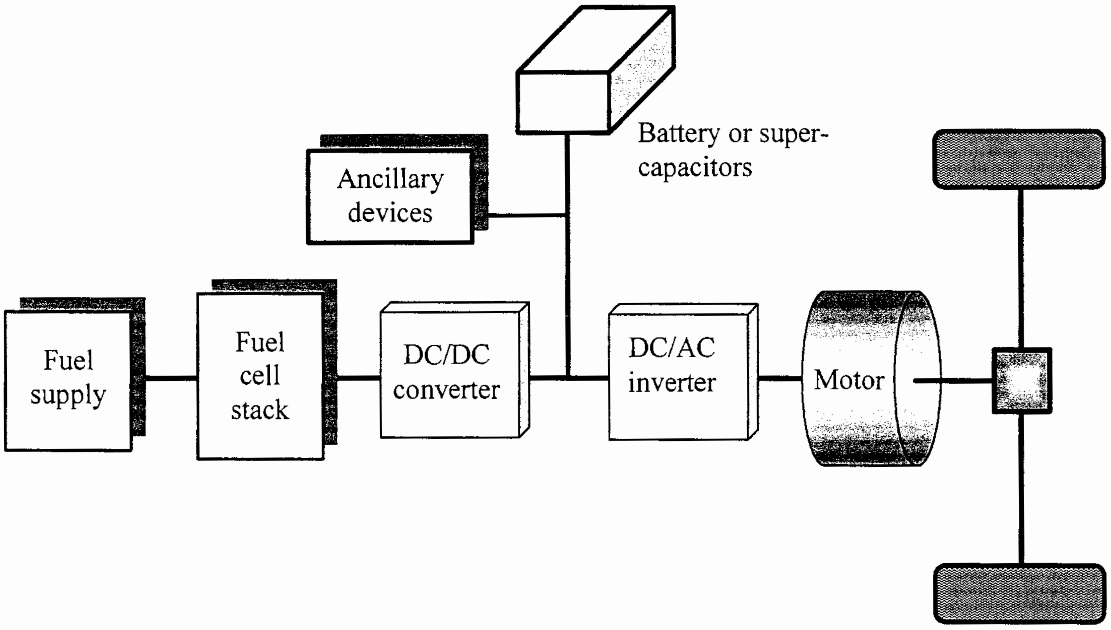

Figure 1

3. A passenger vehicle is fitted with an electric drive train which comprises a battery, a traction brushless dc permanent magnet motor and an IGBT power electronic controller. The traction motor is connected to the vehicle front wheels via a fixed ratio transmission.

Vehicle:

Gross weight	$m = 1200\,\text{kg}$
Rolling resistance coefficient	$\lambda_f = 0.009$
Drag coefficient	$C_d = 0.35$
Frontal area	$A_f = 1.6\ \text{m}^2$
Wheel rolling radius	$r_w = 296.5$ mm

Transmission:

Fixed ratio	$R_t = 10/56$
Efficiency	$\eta_t = 95\%$

(You may assume the gravitational acceleration $g = 9.81 m/s^2$ *and the density of air* $\rho_a = 1.225\ \text{kg/m}^3$*)*

a. Cite the advantages and disadvantages of super capacitors. **(3)**

b. When the traction motor is delivering a maximum torque of $T_p = 72\text{Nm}$, and the vehicle accelerates from standstill to a speed $v_c = 60\text{MPH}$:

i) Listing any assumptions that you make, calculate the traction force *F*. **(4)**

ii) Calculate the time it takes the vehicle to reach the speed $v_c = 60\text{MPH}$. **(3)**

iii) Calculate the energy delivered by the drive-train. **(3)**

iv) Calculate the kinetic energy of the vehicle at the speed $v_c = 60\text{MPH}$ and discuss any discrepancies with the energy delivered by the drive-train. **(2)**

(For a constant traction force, the differential equation describing the motion of a vehicle can be written as: $p\frac{dv}{dt} = q^2 - v^2$*. where* p *and* q *are constants, and* v *is the speed of the vehicle, and the solution of the equation is given by:* $v(t) = q\tanh\left(\frac{q}{p}t + C\right)$*; where* $C = \tanh^{-1}\left(\frac{v_o}{q}\right)$ *and* v_o *is the initial speed of the vehicle. You may also assume that* $\int \tanh(ax+b)dx = \frac{1}{a}\ln(\cosh(ax+b))$ *)*

c. Show that for a constant acceleration γ the energy delivered by the drive-train is given by:

$$E = \frac{1}{2}mv^2 + \frac{1}{2}\lambda_f mg\frac{v}{\gamma} + \frac{1}{8}C_d\rho_a A_f\frac{v^4}{\gamma}$$ **(5)**

4. a. A parallel-hybrid vehicle is equipped with a 4-speed gearbox, a 30kW permanent magnet brushless DC machine, connected to the battery via an IGBT power electronic controller.

The vehicle and traction system have the following parameters:

Vehicle:

Gross weight	$m = 1900\,\text{kg}$
Rolling resistance coefficient	$\lambda_f = 0.013$
Drag coefficient	$C_d = 0.37$
Frontal area	A_f=2.45 m^2
Wheel rolling radius	r_w=296.5 mm

(You may assume the gravitational acceleration $g = 9.81\,m/s^2$ *)*

Transmission:

Gearbox

Gear	Ratio R_g	***Efficiency*** η_g ***(%)***
1st	12/41	93.24
2nd	21/38	94.06
3rd	31/35	94.25
4th	43/35	94.52

Differential

Ratio R_d = 18/62

Losses: negligible

Nickel-Cadmium Battery:

Open circuit voltage $E_o = 200 - 0.25 Q_d \quad (V)$

Internal resistance $R_i = 100 + 1.25 Q_d \; (m\Omega)$

Q_d: State of discharge in (%) (100% as fully discharged).

Traction machine and converter:

The combined losses of the drive-train, excluding the battery, are given by:

$$L_d = 5T + 3.75\times10^{-2}\,T^2 + 3.65\times10^{-3}\,\Omega^2$$

where, T and Ω are the torque and speed of the traction motor machine.

Draw a schematic showing a basic parallel-hybrid drive-train and major energy flow paths, and list its main features. **(4)**

b. Calculate the torque T and the speed Ω of the traction motor and the output power P_d of the battery, when 3rd gear is selected and the vehicle is cruising at a speed of 30MPH into a headwind v_w = 20MPH. **(6)**

c. Assuming the power delivered by the battery is P_d = 7.85kW, calculate its efficiency when Q_d=50%. **(5)**

d. When 3rd gear is selected and no mechanical or re-generative braking is applied, calculate the maximum <u>downwards</u> inclination angle α, for which the vehicle can travel at constant speed of 30MPH into a headwind v_w = 20MPH. **(5)**

(You may assume that the rolling resistance is independent of the inclination angle α and that the iron loss of the traction machine at a speed Ω is given by $P_i = 3.65\times10^{-3}\Omega^2$)

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