Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2011-12 (2.0 hours)

EEE6021 Energy Utilisation

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.** In a solid oxide fuel cell (SOFC), the chemical reactions at the anode and cathode are described by the following equations:

$$Anode: 2H_2 + 2O^{2-} \rightarrow 2H_2O + 4e^-$$

$$Cathode: O_2 + 4e^- \rightarrow 2O^{2-}$$

where O^{2-} denotes the oxygen ion.

Derive an expression for the ideal electromotive force (EMF) of the fuel cell. State any assumption used in the derivation. **(8)**

b. The change of molar specific Gibbs free energy of formation, $\Delta \bar{g}_f$, for the SOFC operating at 800 ^{o}C and standard pressure is -188.6 (kJ/mole)

(i) Calculate the maximum possible reversible open circuit voltage of the fuel cell **(2)**

(ii) Given the "high heating value" of hydrogen fuel being 285.84 (kJ/mole), calculate the maximum possible conversion efficiency of the fuel cell. **(3)**

(iii) If oxygen is supplied at the pressure of 6.0 bar from air with 20.95% concentration and pure hydrogen is used at the same pressure, calculate the reversible open circuit voltage of the fuel cell. Assume the ratio of partial pressure of water steam to the standard pressure is 5. **(5)**

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

c. Describe the main cause of the losses in the high temperature SOFC. **(2)**

2. **a.** Describe what is meant by "mass transportation loss" in fuel cells, and how it affects fuel cell output voltage with the aid of any appropriate equation. **(3)**

b. A 25cm x 25cm PEM fuel cell consumes 0.12g of hydrogen per minute. The cell is connected to a resistive load and outputs 250A current. The change of molar specific Gibbs free energy of formation of the fuel cell operating at 100 ^oC is -225.2 (kJ/mole). Calculate the efficiency of the fuel cell given the higher heating value of hydrogen being 285.84 kJ/mole. The relevant constants for the operation are given in Table 2.1. **(8)**

Table 2.1

Constant	PEMFC at 100 ^0C
i_n (mA/cm^2)	2
r (kΩcm^2)	3.0 x 10^{-5}
i_0 (mA/cm^2)	0.067
A (V)	0.06
B (V)	0.05
i_l (mA/cm^2)	900

c. Figure 2.1 shows the equivalent circuit which represents the dynamic behaviour of a hydrogen fuel cell. Define each component and explain their physical significance. **(5)**

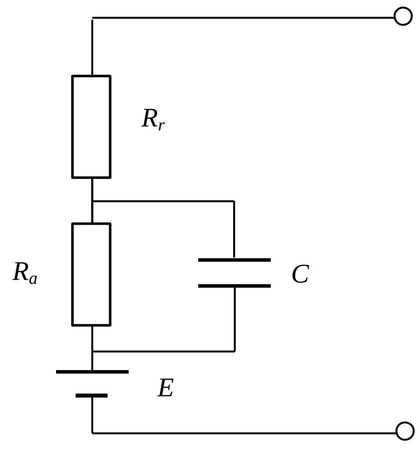

Figure 2.1

d. Derive the frequency response of the fuel cell impedance and describe how the parameters of the circuit shown in Figure 2.1 can be identified from the frequency response. **(4)**

3. A passenger vehicle is fitted with an electric drive train which comprises a battery, a 45kW 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	$r_w = 296.5\ \text{mm}$

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

Transmission:	Fixed ratio (output speed/input speed)	$R_t = 10/56$
	Efficiency	$\eta_t = 95\%$

a. Draw a schematic showing a basic electric drive-train and list its main features. **(4)**

b. For a constant traction force and on road with an upward inclination angle, α, show that the differential equation describing the motion of a vehicle can be written as: $p\dfrac{dv}{dt} = q^2 - v^2$

and show that its solution is given by:

$$v(t) = q\tanh\left(\frac{q}{p}t + C\right)$$

where q, p and C are constants. **(6)**

You may also assume that: $\displaystyle\int \frac{dx}{\left(1-x^2\right)} = \tanh^{-1}(x)$

c. When the traction motor is delivering the maximum torque $T_p = 72\text{Nm}$ on a road with an upward inclination angle $\alpha = 2^{\circ}$:

i. Calculate the time during which the vehicle will reach a speed of $v_c = 40$ MPH.

ii. Calculate the energy delivered by the drive train to increase the vehicle speed from 0 to $v_c = 40$ MPH. **(10)**

You may also assume that:

$\displaystyle\int \tanh(ax+b)\,dx = \frac{1}{a}\ln\left(\cosh(ax+b)\right)$, a and b are constants.

4. A parallel-hybrid saloon vehicle is equipped with a 5-speed gearbox, a 45kW 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	$m = 1630\,\text{kg}$
	Rolling resistance coefficient	$\lambda_f = 0.027$
	Drag coefficient	$C_d = 0.34$
	Frontal area	$A_f = 2.1\ \text{m}^2$
	Wheel rolling radius	$r_w = 321.5\ \text{mm}$

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

Transmission:

Gearbox

Gear	ratio	***Loss coefficients***		
		a	b	c
1st	0.2647	-0.1927	-1.39×10^{-3}	0.9324
2nd	0.4595	-0.2578	-1.33×10^{-3}	0.9406
3rd	0.6998	-0.6086	-1.11×10^{-3}	0.9425
4th	0.9718	-0.8284	-1.76×10^{-3}	0.9452
5th	1.1933	-0.9884	-1.96×10^{-3}	0.9482

(You may assume that the efficiency of the gearbox is given by: $\eta_t = \dfrac{a + b\Omega_i + cT_i}{T_i}$ *; where,* T_i *and* Ω_i *are the input torque and speed, respectively)*

Differential

Ratio: 0.2703

Losses : negligible

Traction machine and power electronics:

The combined losses of the traction motor and power electronic controller are given by:

$$L_e = 7.5T + 7.5\times10^{-2}T^2 + 3.65\times10^{-3}\Omega^2 .$$

where, T and Ω are the torque (Nm) and speed (rad/s) of the traction motor, respectively.

Nickel-Cadmium Battery:

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

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

Q_d : State of discharge in (%).

a. Draw a schematic showing a basic series-hybrid drive-train and describe its main features. Label major energy flow routes through the drive-train. **(4)**

b. Show that the combined losses of the traction motor, the power electronic controller and the transmission is given by:

$$L_d = 5T + 3.75\times10^{-2}T^2 + (1-c)T\Omega - a\Omega + \left(3.65\times10^{-3} - b\right)\Omega^2$$

where, a, b, and c are the loss coefficients of the transmission. **(4)**

c. When 3rd gear is selected and the vehicle is cruising at a speed of 30MPH:

i. Calculate the efficiency of the drive-train when the battery is excluded.

ii. Calculate the current I delivered by the battery and its terminal voltage V for a state of discharge Q_d =50%.

iii. Calculate the efficiency of the drive-train when the battery is included, for a state of discharge Q_d =50%. **(12)**

JBW / KA