Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2013-14 (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.** Describe, with the aid of an appropriate diagram, the basic principle of operation of alkaline electrolyte hydrogen fuel cells. **(4)**

b. In a methanol fuel cell, two methanol molecules (CH_3OH) react with three oxygen molecules (O_2) to form four water molecules (H_2O) and two carbon dioxide (CO_2) molecules. The process releases 12 electrons. **(5)**

$$2CH_3OH + 3O_2 \Rightarrow 4H_2O + 2CO_2 + 12e^-$$

For such an ideal system the change of molar specific Gibbs free energy of formation $\Delta\bar{g}_f$ of the fuel cell is fully converted into electrical energy, show that the reversible open-circuit voltage of the fuel cell is given by:

$$E = -\frac{\Delta\bar{g}_f}{6F}$$

where F is the Faraday constant.

c. For each mole of methanol used in the methanol fuel cell, the reaction releases 698.2 kJ energy at 100°C under the standard pressure (0.1 MPa or 1 bar).

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

(ii) If the supply pressure of the methanol varies from 1 bar to 2 bars and other operational conditions are the same, calculate the change in the maximum reversible open-circuit voltage of the fuel cell. **(5)**

(iii) If oxygen is supplied at a pressure of 2 bars from air with 20.95% oxygen concentration, and pure methanol is used at the same pressure with a fuel utilisation factor of 95%, the reaction produces water vapour and carbon dioxide at a pressure of 1.8 bars. Calculate the maximum theoretical efficiency of the operation at 100 ^{0}C, given the "high heating value" of methanol being 790 (kJ/mole). **(4)**

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

2. **a.** Figure 1 shows the output voltage characteristic of a solid oxide fuel cell (SOFC) operating at 800 ^{0}C. Discuss the key features of the characteristic, and identify the main causes of the cell voltage reduction from the ideal value of 1.0V. **(10)**

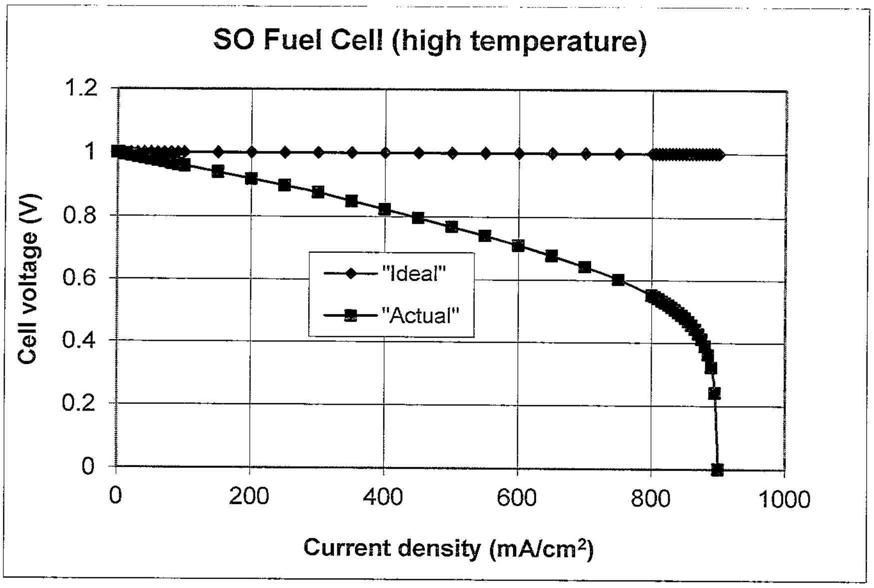

Figure 1

b. Calculate the output voltage of the SOFC operating at 800C^0 and delivering a current density of 600 mA/cm^2, the relevant constants for the operation being given in Table 1. **(4)**

Table 1

Constant	SOFC at 800 ^{0}C
E(V)	1.0
i_n (mA/cm^2)	2
r (kΩcm^2)	3.0 x 10^{-4}
i_0 (mA/cm^2)	300
A (V)	0.03
B (V)	0.08
i_l (mA/cm^2)	900

c. Describe the key effect that influences the electrical dynamic behaviour of a fuel cell and how this effect can be represented in an equivalent circuit. **(6)**

3. An electric scooter 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	$m = 250\,\text{kg}$
	Rolling resistance coefficient	$\lambda_f = 0.009$
	Drag coefficient	$C_d = 0.6$
	Frontal area	A_f=0.8 m^2
	Wheel rolling radius	r_w=160 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)

Epicyclic gearbox:	Fixed ratio	$R_t = 21/38$
	Efficiency	$\eta_t = 95\%$

a. Draw a schematic showing a basic series hybrid drive-train and cite its main features.

(4)

b. When the vehicle is travelling on a flat road into a headwind of speed v_w. Noting any assumptions that you make, show that for a constant traction force F, the differential equation describing the motion of the vehicle can be written as:

$$p\frac{dv_a}{dt} = q^2 - v_a^2 \quad \text{or} \quad p\frac{dv_a}{dt} = -q^2 - v_a^2$$

Where p and q are constants, and v_a is the air speed with respect to the vehicle.

(4)

c. When the vehicle is travelling on a flat road into a headwind $v_w = 15$MPH, and the traction motor is delivering the maximum torque of $T = 30$Nm:

i. Calculate the time it would take the vehicle to accelerate from 0MPH to 30MPH.
ii. Calculate the energy delivered by the drive-train.

(6)

d. The vehicle was cruising at a constant speed of 30MPH into a headwind $v_w =$ 15MPH. If the headwind disappears and the torque produced by the brushless motor is kept the same, calculate the time it would take the vehicle to reach 40MPH.

(6)

(You may assume that the solution of the differential equation $p\frac{dv_a}{dt} = q^2 - v_a^2$ is given by: $v_a(t) = q\tanh\left(\frac{q}{p}t + C\right)$; where $C = \tanh^{-1}\left(\frac{v_o}{q}\right)$ and v_o the initial air speed. You may also assume that: $\int \tanh(ax+b)dx = \frac{1}{a}\ln(\cosh(ax+b))$)

4. A parallel-hybrid saloon is equipped with a 5-speed gearbox, a 45kW permanent magnet brushless DC machine, which is 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 m^2
	Wheel rolling radius	r_w=321.5 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:

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

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 (%).

The combined losses of the drive-train, excluding the battery, are 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, T and Ω are the torque and speed of the traction motor, respectively, and a, b, and c are the loss coefficients of the transmission.

a. Calculate the efficiency of drive-train, excluding the battery, when 3rd gear is selected and the vehicle is cruising at a speed of 30MPH:

i. with no headwind.

ii. with a headwind v_w = 30MPH.

(10)

b. When the state of charge is 80%, calculate the efficiency of the battery when it is delivering a power P_d = 10 kW.

(5)

c. When 3rd gear is selected and the vehicle is travelling on a road with a downwards inclination angle $\alpha = 5^o$, neglecting the losses in the transmission, the traction machine and the power electronic converter, calculate the power absorbed by the battery P_d, when re-generative braking is applied in order to limit the speed of the vehicle to 30MPH.

(5)

KA/JBW