Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2014-15 (3.0 hours)

EEE6202 Energy Storage Management

Answer **FOUR** questions. **No marks will be awarded for solutions to a fifth 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.** Explain with the aid of a suitable diagram, the operation of a basic fuel cell constructed with an acid electrolyte. Your explanation should also include the anode and cathode reaction equations. **(10)**

b. **i)** Using the information in Table 1, calculate the open circuit potential of a hydrogen fuel cell operating at room temperature (25^{o}C). **(4)**

ii) How many fuel cells would need to be connected in series to power a 5V cell phone? (State any assumptions that you make). **(2)**

Gibbs free energy of formation for water as a function of reaction temperature		
Form of H_2O	Temperature ^{0}C	$\Delta\bar{g}_f$ (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

Table 1

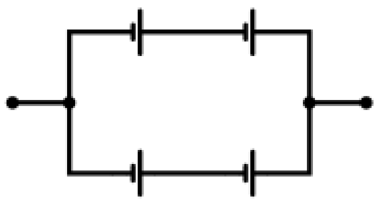
c. Would a Phosphoric Acid Fuel Cell (PAFC) be a suitable choice to power a small portable piece of equipment? Justify your answer. **(4)**

2. **a.** **i)** An Electric Vehicle battery is chosen for 2nd-life re-use as a static Battery Energy Storage System (BESS) for a domestic house with a 4kW photovoltaic system. Describe with the aid of circuit and phasor diagrams, the operation of a galvanically isolated, grid-tied, four-switch-converter capable of bidirectional power transfer between the battery and the single-phase utility of the grid. **(6)**

ii) Considering a 112.2V – 191.4V DC voltage swing for a NiMH-based battery to be used in the BESS calculate the necessary transformer turns ratio and maximum allowable grid-side leakage-inductance of the isolation transformer if the 4kW single-phase (50Hz, 230Vrms) supply is subject to +/- 10% variation and the transformer is assumed to be 90% efficient. State any assumptions you make. **(6)**

b. **i)** An Electric Vehicle battery is removed from the vehicle when the State-of-Health reaches 80% and used as an alternative to the NiMH pack of the Energy Storage System described in **2.a.** The alternative battery pack is made of 48 series-connected modules that use Lithium-based cells. Each module is made of four cells with the individual operating parameters (from new) shown in Figure 1. Calculate the DC voltage swing that the 4kW four-switch bidirectional converter must now accommodate, and the nominal storage capacity of the installed static energy storage system. **(3)**

ii) During a power failure of the grid, the fully-charged BESS and 4kW photovoltaic system are both isolated from the single-phase supply, and used to provide emergency lighting which requires a constant 8A DC current supply. The photovoltaic system is configured to be able to supply a current of 6A DC when in emergency mode. If the power failure occurs at five minutes past midnight (00:05am), will the emergency lighting still be operable at 7:30am if sunrise occurs at 6:30am? State any assumptions made. **(5)**



Nominal voltage	Float-charge voltage	Cut-off voltage	Capacity per cell
3.8V	4.2V	2.5V	33Ah

Figure 1 – Four-cell module used in pack and individual cell parameters

3. **a.** With the aid of a suitable diagram, detail the key components required in a high-voltage multi-cell battery pack. The polarity of the cathode and anode should be clearly identified. **(5)**

b. Describe 6 key functions of a Battery Management System for large battery packs. **(6)**

c. **i)** A battery pack consisting of four 80V nominal modules connected in series will be balanced using an uncontrolled passive balancing technique during Constant Current-Constant Voltage (CC-CV) charging mode as shown in Figure 2. Before charging or balancing starts, the battery pack steady-state terminal voltage (Vpack) is measured by the BMS to be 100V. Assuming that the 200Ω balancing resistors can be applied to the modules B1, B2, B3 and B4 instantaneously, calculate the instantaneous power dissipated in each resistor if the cell capacities are subject to the variations shown (state any assumptions made). **(4)**

ii) During the CC-CV charging process a charging current of 8A is applied to the pack until the float-charge level of 100V per module is reached. Calculate the maximum instantaneous power dissipated by the balancing system during the charging process, stating any assumptions made. How could the system be improved to reduce heating effects in the pack? **(2)**

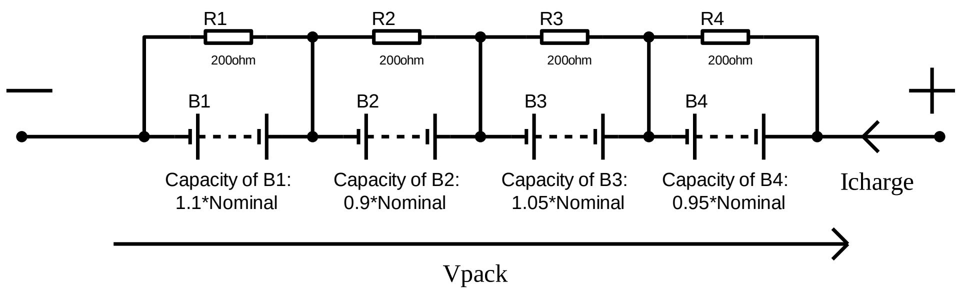


Figure 2 – Uncontrolled passive balancing system for a battery pack

d. Describe three active methods of string balancing for large battery packs. **(3)**

4. **a.** Explain with the aid of suitable diagrams and chemical reaction equations, the basic composition and discharge process of a NiMH cell from 100% State-of-Charge (SoC) until fully discharged. State any assumptions made and detail the role that Potassium ions in the electrolyte have in the process. **(10)**

b. A NiMH cell is fully discharged from 100% SoC with a constant current at the 0.5C rate. Sketch the full discharge curve of the terminal voltage over time. **(3)**

c. A NiMH cell is now charged from 0% SoC with a constant current at the 1C rate. The charger does not include a timer to prevent overcharge. Detail two alternative methods of preventing dangerous overcharge of the cell. Include a sketch of any measurable quantities during the full duration of charging. **(4)**

d. Describe with the aid of a diagram, a manufacturing process by which excessive gassing of a NiMH cell can be prevented. **(3)**

5. **a.** Explain with the aid of a suitable diagram, the main components in an energy storage system, and specifically, how a flywheel could be used within such a system. **(8)**

b. Explain why a containment vessel is a necessary component for an energy storage flywheel. **(3)**

c. Why is a flywheel often operated in a vacuum? **(3)**

d. Theoretically, how much more energy could be stored per kg of material in a flywheel manufactured from a constant stress disk of Kevlar, in comparison with a thin rim flywheel manufactured from Carbon steel? **(6)**

Flywheel Shape	K
Constant stress disk	0.931
Constant thickness disc	0.606
Thin rim	0.500
Constant stress bar	0.500
Rod or circular brush	0.333
Flat pierced disc	0.305

Table 2 – Flywheel Shape Factor, K

Flywheel material	Specific strength (kJ/kg)
Cast iron	19
Carbon steel	44
Alloy steel	100
Wood (beech)	130
Kevlar	1700
S-glass	1900
Graphite	8900

Table 3 – Flywheel Material Specific Strengths

6. **a.** Describe with the aid of a circuit diagram the 2nd-order equivalent circuit model introduced by J. Randles for modelling the State-of-Charge (SoC) and State-of-Health (SoH) of lead-acid cells. **(5)**

b. A 12V, 45Ah nominal lead-acid battery has a capacity range of between 43Ah and 47Ah when it is pulse discharged from 100% SoC with a series of measured 10A pulses (1600 seconds in duration) until the battery reaches full discharge at a cut-off voltage of less than 10.5V. Considering that the final pulse is stopped by the controller after 490s, calculate the number of pulses that the controller initiated, and thereby find the actual capacity in Ah of the battery. **(2)**

c. The initial Open-Circuit Voltage (OCV) of a battery at 100% SoC is measured as 13.26V and after each 10A 1600s pulse the battery is allowed to relax to steady state for 3 hours before another OCV measurement is taken. The sequence of voltages measured during the test is given below in Table 4. Considering a 46Ah battery calculate the capacity remaining after the last pulse and sketch the nonlinear SoC vs. OCV curve and estimate a suitable linear approximation of the main capacitive charge store described by Randles. **(9)**

V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
13.1V	12.94V	12.79V	12.63V	12.46V	12.29V	12.11V	11.93V	11.73V	11.44V

Table 4 – OCV for a 12V lead-acid battery under 10A pulsed-discharge.

d. Considering the magnified view of the battery terminal voltage during a single 10A pulse discharge given in Figure 3, estimate the three remaining equivalent circuit parameters of the Randles' model (The self-discharge resistance may be neglected).

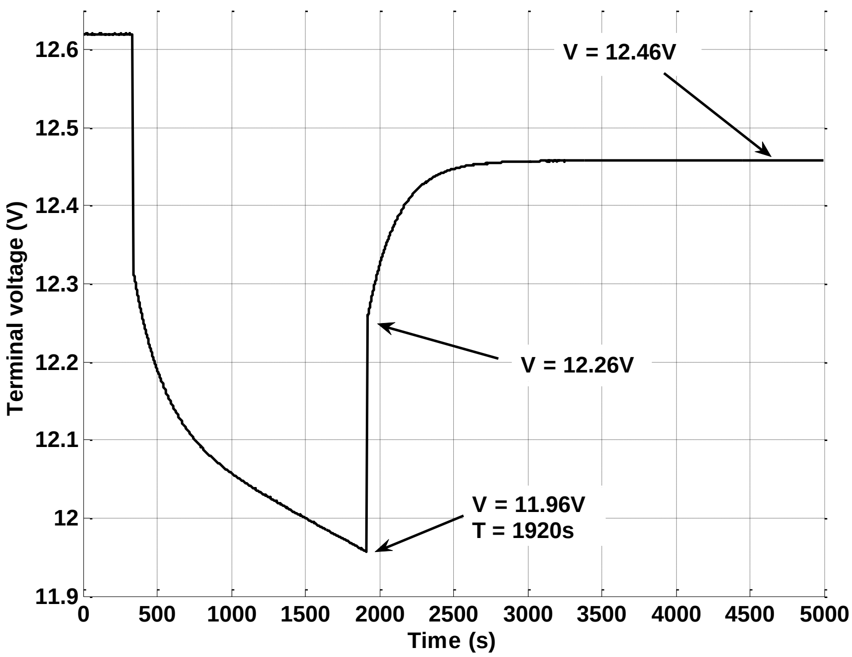


Figure 3 – Terminal voltage of a 12V lead-acid battery under pulsed-discharge.

(4)

CG/DAS/MF