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Mid Term Examinations - October 2026

Date: 07/10/2026 **Time:** 02:00 PM - 03:30 PM

Course Code: EEE3501 **Course Name:** Battery Management Systems

Semester: Fifth Semester **Max. Marks:** 50 **Weightage:** 50%

CO - Levels	CO1	CO2	CO3	CO4	CO5
Marks	12	22	12	22	22

PART A: Answer Following Questions. 10 M

Q.N.	Questions	M	CO	BT
1	Explain why the terminal voltage of a secondary battery cell reaches its lower cutoff voltage faster when operated under high discharge C-rates.	2	CO1	BT2
2	Outline the principle of the switched-resistor method used by a BMS to detect high-voltage DC isolation degradation relative to chassis ground.	2	CO2	BT2
3	Compare a Centralized BMS architecture with a Modular (Master–Slave) architecture with respect to wiring harness complexity and electrical noise immunity.	2	CO3	BT2
4	Identify the cathode material, anode material, and nominal cell voltage for both Lithium Iron Phosphate (LFP) and Nickel Manganese Cobalt (NMC) chemistries.	2	CO4	BT1
5	Write the continuous-time governing equations for the terminal voltage $V_t(t)$ and the polarization voltage dynamics $\frac{dV_1(t)}{dt}$ in a 1-RC Thevenin battery model.	2	CO5	BT1

PART B : Answer Any 1 Following Questions. 10 M

Q.N.	Questions	M	CO	BT
6	1. Explain the electrochemical definitions of nominal cell voltage, gravimetric specific energy ($\mathrm{Wh/kg}$), volumetric energy density ($\mathrm{Wh/L}$), and Coulombic efficiency. Clarify how high discharge C-rates cause premature terminal voltage drop to the cutoff limit (V_{cutoff}) despite active lithium remaining in the electrodes. **[4 Marks]** 2. An electric vehicle powertrain requires a nominal DC bus voltage of $V_{\mathrm{nom}} \approx 400\,\mathrm{V}$ and a total usable energy of $E_{\mathrm{usable}} = 54\,\mathrm{kWh}$ across an allowable State of Charge window of 10% to 90% ($\Delta\mathrm{SoC} = 80\%$). The selected cylindrical NMC cells have $V_{\mathrm{cell}} = 3.65\,\mathrm{V}$, nominal capacity $Q_{\mathrm{cell}} = 4.8\,\mathrm{Ah}$, and mass $m_{\mathrm{cell}} = 68\,\mathrm{g}$. **[6 Marks]** 1. Calculate the series-parallel configuration ($N_s\mathrm{s}N_p\mathrm{p}$) and total cell count. 2. Determine the actual gross energy capacity (E_{actual}) and total bare cell pack mass in kilograms.	10	CO1	BT3

7	1. Compare Distributed and Wireless BMS (wBMS) architectures with representative schematics. Detail the operational advantages and engineering trade-offs of mounting measurement hardware directly on cell terminals versus utilizing 2.4 GHz wireless communication nodes. **[4 Marks]** 2. An industrial vehicle requires a 360 V nominal traction pack with an energy storage capacity of 72 kWh. **[6 Marks]** 1. Determine the number of series cells (N_s), parallel strings (N_p), and total cell count required using NMC Li-ion cells rated at $3.6\ \text{V}$ and $50\ \text{Ah}$. 2. Determine the configuration (N_s, N_p, and total cell count) if the pack is constructed using Lead-Acid cells rated at *2.0* V and *100* Ah. 3. Calculate the percentage reduction in BMS Analog Front End (AFE) voltage sensing channels achieved by selecting the Li-ion chemistry over Lead-Acid.	10	CO2	BT3

PART C: Answer Any 1 Following Questions. 10 M				
Q.N.	**Questions**	**M**	**CO**	**BT**
8	1. Describe the circuit architecture of a 2-RC Dual Polarization (DP) Equivalent Circuit Model. Differentiate the physical time scales and underlying electrochemical mechanisms governing the fast RC branch versus the slow RC branch. State why exact Zero-Order Hold (ZOH) discretization is favored over Forward Euler approximations in discrete microcontroller code. **[4 Marks]** 2. A high-power pouch cell has an open-circuit voltage $V_{oc} = 3.820\ \text{V}$ and follows a 2-RC ECM with the following parameters: $R_0 = 1.80\ \text{m}\Omega$; Fast branch: $R_1 = 1.20\ \text{m}\Omega$, $\tau_1 = 1.50\ \text{s}$; Slow branch: $R_2 = 2.50\ \text{m}\Omega$, $\tau_2 = 30.0\ \text{s}$. Starting from complete rest ($V_1(0) = 0\ \text{V}, V_2(0) = 0\ \text{V}$), an acceleration discharge current of $I_L = 120.0\ \text{A}$ is applied for $t = 6.0\ \text{s}$. Neglecting capacity depletion over this short pulse: **[6 Marks]** 1. Compute the fast-branch overvoltage $V_1(6\ \text{s})$ and slow-branch overvoltage $V_2(6\ \text{s})$. 2. Calculate the total polarization overvoltage (η_{pol}) and the instantaneous ohmic drop (ΔV_0). 3. Determine the terminal voltage immediately before load interruption ($V_t(6^-\ \text{s})$) and immediately after interruption ($V_t(6^+\ \text{s})$).	10	CO3	BT3
9	1. Explain the "Weakest Cell Phenomenon" (Bucket Theory) in multi-cell series battery strings during charging and discharging. Compare passive dissipative balancing with active non-dissipative balancing across operating efficiency, thermal management impact, system cost, and execution time windows. **[4 Marks]** 2. A 4S LiFePO_4 battery pack ($Q_n = 60\ \text{Ah}, V_{\text{cell}} = 3.2\ \text{V}$) exhibits an end-of-charge State of Charge mismatch where Cells 1, 2, and 3 are at 96% SoC, but Cell 4 is lagging at 88% SoC ($\Delta\text{SoC} = 8\%$). **[6 Marks]** 1. Calculate the excess charge mismatch (ΔQ) in ampere-hours. 2. If a passive bleed resistor network with $R_{\text{bleed}} = 20\ \Omega$ and duty cycle $D = 100\%$ is used, compute the bleed current (I_{bleed}), total time needed to balance the pack, and total electrical energy wasted as heat across the three bled cells. 3. If an active inductive balancing system redistributes charge into Cell 4 at an average current of $I_{\text{active}} = 1.6\ \text{A}$ with an efficiency of $\eta = 85\%$, compute the required balancing time and total energy lost in conversion. Analyze the operational advantages of the active approach.	10	CO4	BT3

PART D: Answer Any 1 Following Questions. 10 M				
Q.N.	**Questions**	**M**	**CO**	**BT**
10	1. Illustrate the architecture of a Switched-Resistor Isolation Monitoring Network used to evaluate chassis insulation integrity (R_{iso+}, R_{iso-}). Explain the two-phase switching sequence using opto-isolated switches (S_1, S_2) and precision measurement resistors (R_m). State the minimum isolation resistance per volt required under ISO 6469-3 standards for DC high-voltage buses. **[4 Marks]** 2. An 800 V nominal EV battery pack undergoes an isolation diagnostic check using an internal measuring resistance $R_m = 1\ \text{M}\Omega$ ($1000\ \text{k}\Omega$). **[6 Marks]** ■ In the baseline state (switches open), positive-to-chassis and negative-to-chassis voltages are measured as $V_{p0} = 500\ \text{V}$ and $V_{n0} = 300\ \text{V}$. ■ In the switched state (switch S_2 closed), the positive-to-chassis voltage drops to $V_{p1} = 400\ \text{V}$. 1. Calculate the individual insulation leakage resistances R_{iso+} and R_{iso-}. 2. Calculate the total equivalent parallel isolation resistance (R_{iso}) and determine the system's normalized safety rating in Ω/V. Evaluate whether this pack complies with the ISO 6469-3 safety threshold ($500\ \Omega/\text{V}$) and specify the mandatory action for the BMS controller.	10	CO5	BT3
11	1. Contrast Lithium Iron Phosphate (LiFePO_4) and Nickel Manganese Cobalt (NMC) cathode chemistries regarding structural thermal stability, specific energy, and the slope of their Open-Circuit Voltage (V_{oc}) vs. SoC curves. **[2 Marks]** 2. An off-grid solar storage system requires a 48 V nominal DC bus and a usable storage capacity of 9.6 kWh across a safe depth-of-discharge window of 20% to 90% ($\Delta\text{SoC} = 70\%$). The design utilizes prismatic LiFePO_4 cells rated at 3.2 V and 100 Ah. Determine the series-parallel configuration ($N_s\text{s}N_p\text{p}$), total cell count, and gross installed energy capacity in kWh. **[3 Mark]** 3. Explain the architectural advantages of a Wireless BMS (wBMS) over a wired Modular BMS. Highlight two key engineering challenges introduced by deploying RF transceivers inside a sealed metallic enclosure. **[2 Marks]** 4. A telecommunications backup battery requires a 48 V nominal bus with a storage capacity of 12 kWh. Compare pack architectures when choosing between: System A: NMC Li-ion cells rated at 3.7 V, 40 Ah System B: Lead-Acid cells rated at 2.0 V, 50 Ah Calculate the series cell count (N_s) for each system and compute the percentage reduction in BMS Analog Front End (AFE) sensing channels achieved by selecting System A over System B. **[3 Marks]**	10	CO2	BT3

PART E: Answer Any 1 Following Questions. 10 M				
Q.N.	**Questions**	**M**	**CO**	**BT**

12	1. Explain the electrochemical origin of Open-Circuit Voltage (OCV) hysteresis in lithium-ion batteries. Explain why failing to include a dynamic hysteresis state in the equivalent circuit model leads to severe State of Charge (SoC) estimation errors when using an Extended Kalman Filter (EKF) on $LiFePO_4$ cells. **[2 Marks]** 2. A 2-RC Dual Polarization model of an NMC cell has parameters: $R_0 = 2.0\ \text{m}\Omega$, fast branch $R_1 = 1.0\ \text{m}\Omega$ ($\tau_1 = 2.0\ \text{s}$), and slow branch $R_2 = 3.0\ \text{m}\Omega$ ($\tau_2 = 40.0\ \text{s}$). The cell has rested at an open-circuit potential of $V_{oc} = 4.10\ \text{V}$. A discharge pulse of $I_L = 80.0\ \text{A}$ is applied for $t = 4.0\ \text{s}$. Calculate the overvoltage across the fast branch $V_1(4\ \text{s})$, the slow branch $V_2(4\ \text{s})$, the instantaneous ohmic drop ΔV_0, and the cell terminal voltage $V_t(4^-\ \text{s})$ right before the load is removed. **[4 Marks]** 3 . An active switched-inductor balancing circuit transfers charge from an overcharged cell ($V_1 = 4.1\ \text{V}$) to a lower cell ($V_2 = 3.3\ \text{V}$) using an inductor $L = 100\ \mu\text{H}$ operating in Discontinuous Conduction Mode (DCM) at a switching frequency $f_{sw} = 50\ \text{kHz}$. The primary switch is energized for $t_{on} = 8.0\ \mu\text{s}$ each cycle. Assuming an overall power transfer efficiency of $\eta = 80\%$, compute the peak inductor current I_{pk}, the input power extracted from Cell 1, and the average charging current I_{out} delivered into Cell 2. **[4 Marks]**	10	CO4	BT3
13	1. Describe the operating principle of a Switched-Resistor Isolation Monitoring circuit used in high-voltage electric vehicles. Explain how opto-isolated solid-state switches and precision measurement resistors (R_m) are used to decouple positive-to-chassis and negative-to-chassis leakages without introducing electrical hazards. **[2 Marks]** 2. An EV battery pack with nominal bus potential $V_{pack} = 500\ \text{V}$ undergoes an isolation check using internal measuring resistors $R_m = 1000\ \text{k}\Omega$. In the baseline state (switches open), the chassis voltages are $V_{p0} = 300\ \text{V}$ and $V_{n0} = 200\ \text{V}$ When switch S_2 is closed, the positive-to-chassis voltage drops to $V_{p1} = 240\ \text{V}$ Calculate the positive rail isolation leakage resistance R_{iso+}, the negative rail isolation leakage resistance R_{iso-}, and the total equivalent parallel isolation resistance R_{iso}. Verify whether the pack meets the ISO 6469-3 minimum requirement of $500\ \Omega/\text{V}$. **[4 Marks]** 3. A traction contactor coil with resistance $R_{coil} = 16\ \Omega$ is powered by a 12 V auxiliary battery. During startup, the coil is driven at 100% duty cycle for $t_{pull} = 80\ \text{ms}$ to pull the contacts shut. Once closed, a PWM economizer drops the duty cycle to $D = 20\%$ for steady-state holding. Calculate the power dissipation during pull-in (P_{pull}), average power dissipation during hold mode (P_{hold}), and the net electrical energy saved in joules over a 1-hour driving period compared to operating at an unmodulated 100% duty cycle. **[3 Marks]**	10	CO5	BT3