CBCS SCHEME

USN

18EE752

Seventh Semester B.E. Degree Examination, July/August 2022
Electric Vehicles

Time: 3 hrs. Max. Marks: 100

Note: Answer any FIVE full questions, choosing ONE full question from each module.

Important Note : 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages.
2. Any revealing of identification, appeal to evaluator and /or equations written eg, 42+8 = 50, will be treated as malpractice.

Module-1

1 a. Explain the following terms used in roadway fundamentals:
   i) Roadway position vector
   ii) Tangential roadway length
   iii) Roadway percent grade. **(06 Marks)**

b. A straight roadway has a profile in $x_F - y_F$ plane given by, $f(x_F) = 3.9\sqrt{x_F}$ for $0 \le x_F \le 2$ miles, where x_F and y_F are given in feet.
   i) Plot the roadway
   ii) Find $\beta(x_F)$
   iii) Find the percent grade at $x_F = 1$ mile. **(08 Marks)**

c. Define and derive the instantaneous tractive power delivered by the propulsion unit of the vehicle. Draw and explain the tractive power curve. Also derive the mean or average tractive power developed by the propulsion unit over the acceleration interval 0 to t_f. **(06 Marks)**

OR

2 a. An electric vehicle has the following parameter values. $m = 800kg$, $C_D = 0.2$, $A_F = 2.2m^2$, $C_O = 0.008$, $C_1 = 1.6 \times 10^{-6}s^2/m^2$. Also take density of air $= 1.18kg/m^3$ and acceleration due to gravity $g = 9.81m/s^2$. The vehicle is on level road. It accelerates from 0 to 65mph in 10sec, such that its velocity profile is given by,
   $V(t) = 0.29055t^2$ for $0 \le t \le 10sec$
   i) Calculate $F_{TR}(t)$ for $0 \le t \le 10sec$
   ii) Calculate $P_{TR}(t)$ for $0 \le t \le 10sec$
   iii) Calculate the energy loss due to non-conservative forces.
   iv) Calculate Δe_{TR}. **(10 Marks)**

b. Define road load force and describe its components with relevant equations. **(10 Marks)**

Module-2

3 a. State the advantages of electric vehicles over the IC engine vehicles. Also state the differences in infrastructure between IC Engine vehicles and electric vehicles. **(04 Marks)**

b. Explain the configuration of modern electric vehicle drive train with a neat functional diagram. **(08 Marks)**

c. Define series hybrid electric drive train and explain the configuration of it with a neat diagram by incorporating various operating modes in it. **(08 Marks)**

OR

4 a. Define speed ratio of traction motor in EV. Draw and explain the speed torque characteristics of a typical traction motor with different speed ratios. **(06 Marks)**

b. Define parallel hybrid electric drive train and explain the general configuration of it with a neat diagram by incorporating various operating modes in it. **(08 Marks)**

c. State and explain different types of mechanical coupling used in parallel hybrid electric drive training. **(06 Marks)**

Module-3

5 a. State various requirements for energy storage devices used in automotive applications. Explain the following terms:
   i) Specific energy
   ii) Specific power
   iii) Energy efficiency. **(08 Marks)**

b. Explain the operating principle of lead acid battery with relevant chemical reaction equations. **(06 Marks)**

c. Classify fuel cells into various types based on the type of electrolyte used. **(06 Marks)**

OR

6 a. Develop a fractional depletion model of batteries using two different approaches. **(08 Marks)**

b. Explain about Lithium-ion battery technology with relevant chemical reaction equations and also state the advantages of it. **(08 Marks)**

c. List out various parameters specified in battery by the manufacturers. **(04 Marks)**

Module-4

7 a. Explain the two-quadrant operation of chopper in the following schemes for the control of DC motors in electric vehicles.
   i) Single chopper with a reverse switch
   ii) Class-C two quadrant chopper. **(10 Marks)**

b. Draw and explain the configurations of the following various inverter topologies used for SRM drive in Electric vehicles.
   i) Classic converter
   ii) R-dump inverter
   iii) C-dump inverter. **(10 Marks)**

OR

8 a. Explain the following control schemes used for a BLDC motor drive in EVs.
   i) Torque control scheme ii) Speed control scheme. **(06 Marks)**

b. State the advantages and disadvantages of BLDC motor in electric vehicles. **(04 Marks)**

c. Explain the constant V/f control applicable to induction motor drives for EVs. Also explain the power electronic control scheme for it with a neat block diagram. **(10 Marks)**

Module-5

9 a. Explain various operating patterns of a series hybrid electric drive train for its optimal operation. Also draw a typical series hybrid electric drive train configuration. **(10 Marks)**

b. Explain various control strategies employed in a series hybrid electric drive train for vehicles with different mission requirements. **(10 Marks)**

OR

10 a. Explain the overall configuration of the parallel torque coupling hybrid drive train with a neat schematic diagram. **(06 Marks)**

b. Explain the following control strategies employed in a parallel hybrid electric drive train:
   i) Max SOC-of-PPS control strategy.
   ii) Engine on-off control strategy.
   iii) Constrained engine on-off control strategy. **(14 Marks)**

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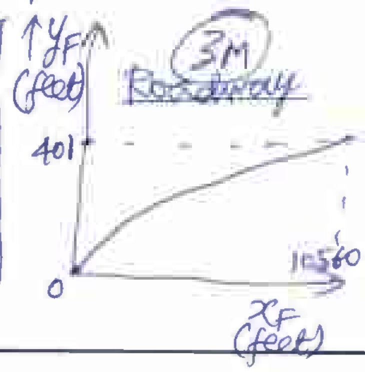
Signature of Scrutinizer

Scheme & Solutions

Subject Title : ELECTRIC VEHICLES **Subject Code :** 18EE752

Question Number	Solution	Marks Allocated
1)a)	Roadway position vector → $\vec{r}(x_F) = x_F \vec{i_F} + y_F \vec{j_F} = x_F \vec{i_F} + f(x_F)\vec{j_F}$ where $y_F = f(x_F)$ is a 2D roadway. x_F → horizontal distance travelled. $a \le x_F \le b$. Direction of motion & distance traversed by the vehicle is easier to express in terms of tangent vector of roadway position vector. $\vec{T}(x_F) = \frac{d\vec{r}}{dx_F} = \vec{i_F} + \frac{df}{dx_F}\vec{j_F}$ (2M)	
	Tangential roadway length:- → Distance traversed along the roadway. → Arc length of $y_F = f(x_F)$ over $a \le x_F \le b$. $\therefore S = \int_a^b \lVert \vec{T}(x_F) \rVert \, dx_F$ where, $\lVert \vec{T}(x_F) \rVert = \sqrt{1 + \left[\frac{df}{dx}\right]^2}$ (distance-norm). (2M)	6M
	Roadway percent grade:- → Vertical rise per 100 units in horizontal distance of roadway with both distances expressed in same units.  $\therefore \%\text{grade} = \frac{\Delta y}{100} \times 100\% = \Delta y\%$. (2M)	
1)b)	$y_F = 3.9\sqrt{x_F}$ $0 \le x_F \le 2$ miles ⇒ $0 \le x_F \le 10560$ feet. Table: x_F / y_F: 0 / 0; 1000 / 123.3; 2000 / 174.4; ⋮ / ⋮; 10560 / 400.8.  (3M) slope angle $\beta = \tan^{-1}\left[\frac{df}{dx}\right]$; $f(x_F) = y_F = 3.9\sqrt{x_F}$; $\therefore \frac{df}{dx} = \frac{1.95}{\sqrt{x_F}}$ (2M); $\therefore \beta = \tan^{-1}\left[\frac{1.95}{\sqrt{x_F}}\right]$	8M

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Question Number	Solution	Marks Allocated

W.k.t. $\tan\beta = \frac{\Delta y}{100} \Rightarrow \frac{\Delta y}{100} = \frac{1.95}{\sqrt{x_F}}$ (3M)

for $x_F = 1\,\text{mile} = 5280$ feet, $\frac{\Delta y}{100} = \frac{1.95}{\sqrt{5280}} = 0.0268$

$\therefore$ % grade $= \frac{\Delta y}{100} \times 100\% = \underline{2.68\%}$

1) c) Instantaneous tractive power delivered $P_{TR}(t) = F_{TR} \times v(t)$.

Where, velocity $v(t) = V_T \tanh(K_2 V_T t)$.

V_T = terminal velocity $= \sqrt{K_1 K_2}$ (2M)

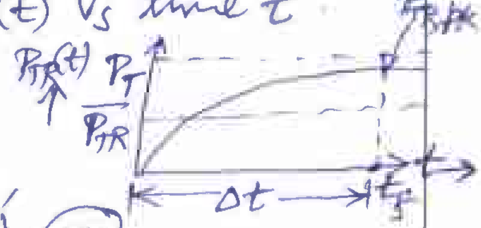
$K_1 = \frac{F_{TR}}{m} - gC_0 > 0$ & $K_2 = \frac{\rho}{2m} C_D A_F + gC_1 > 0$

$\therefore P_{TR}(t) = F_{TR} V_T \tanh(K_2 V_T t) = P_T \tanh(\sqrt{K_1 K_2}\, t)$

where, $P_T = F_{TR} V_T$ = terminal power.

Tractive power curve → $P_{TR}(t)$ Vs time t

→ tractive power required to reach the desired velocity V_f over acceleration interval Δt is,



$P_{TR,pk} = P_T \tanh(\sqrt{K_1 K_2}\, t_f)$. (2M)

mean or average tractive power $\overline{P_{TR}} = \frac{1}{t_f}\int_0^{t_f} P_{TR}(t)\,dt$

$\Rightarrow \overline{P_{TR}} = \frac{P_T}{t_f\sqrt{K_1 K_2}} \ln[\cosh \sqrt{K_1 K_2}\, t_f]$ (2M)

(Derivation of)

6M

2) a) (i) Force balance equation, $F_{TR} - F_{gxT} - F_{AD} - F_{roll} = m\frac{dv}{dt}$

$\Rightarrow F_{TR} = m\frac{dv}{dt} + F_{AD} + F_{roll} = m\frac{dv}{dt} + \frac{\rho}{2} C_D A_F v^2 + mg(C_0 + C_1 v^2)$

$\therefore F_{TR}(t) = 0.02298t^4 + 464.88t + 62.784$ Newtons (2M)

(ii) $P_{TR}(t) = F_{TR}(t) \times v(t)$. (2M)

$\Rightarrow P_{TR}(t) = 135.0709t^3 + 0.006677t^6 + 18.2419t^2$ watts

(iii) Total Non-conservative forces $= F_{AD} + F_{roll}$

$\Rightarrow F_{noncon} = \frac{\rho}{2} C_D A_F v^2 + mg(C_0 + C_1 v^2)$

$\therefore F_{non\text{-}con} = 0.02298t^4 + 62.784$ Newtons → (1M)

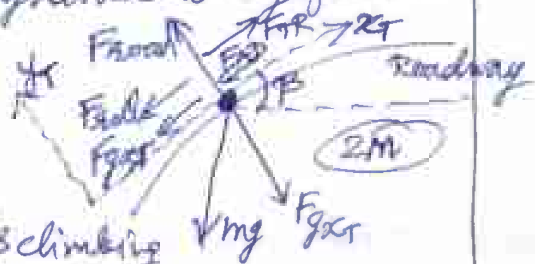
$\therefore$ Power lost $P_{noncon} = v(t) \times F_{noncon} = 18.2419t^2 + 6.6768 \times 10^{-3} t^6$ W. (1M)

$\therefore$ Energy lost $E_{loss} = \int_0^{10} P_{noncon}\,dt = \underline{15618.92}$ Joules → (1M)

(iv) $\Delta e_{TR} = \Delta KE + E_{loss}$

10M

Subject Title : ELECTRIC VEHICLES **Subject Code :** 18EE752

Question Number	Solution	Marks Allocated
	$\Delta KE = \frac{1}{2} m \left[v(t_f)^2 - v(t_0)^2 \right]$ $t_0 = 0$ & $t_f = 10\,sec$ $\Rightarrow \Delta KE = 337{,}677.21$ Joules → (2M) $\therefore \Delta e_{TR} = 353{,}296.13$ Joules → (1M)	
2) b)	Road load force → gravitational force, rolling resistance force and the aerodynamic drag force → (1M) (1M) $F_{RL} = F_{gxT} + F_{roll} + F_{AD}$  (2M) F_{gxT} → depends on slope of roadway. → positive when vehicle is climbing and negative when it is descending. $F_{gxT} = mg \sin\beta$ with description → (2M) F_{roll} → force due to couple which opposes motion of wheel → tangential to roadway and always assists in braking or retarding the motion of vehicle. → can be minimized by keeping tires as inflated as possible. $\therefore F_{roll} = \begin{cases} sgn(v_{xT})\, mg(C_0 + C_1 v_{xT}^2) & \text{if } v_{xT} \neq 0 \\ (F_{TR} - F_{gxT}) & \text{if } v_{xT} = 0 \text{ and } \lvert F_{TR} - F_{gxT} \rvert \leq C_0 mg \\ sgn[F_{TR} - F_{gxT}]\, C_0 mg & \text{if } v_{xT} = 0 \ \& \ \lvert F_{TR} - F_{gxT} \rvert > C_0 mg \end{cases}$ (2M) F_{AD} → Force due to viscous resistance & pressure distribution over the body of air working against the motion of vehicle. (2M) $F_{AD} = sgn(v_{xT}) \{0.5 \rho C_D A_F (v_{xT} + v_0)^2\}$	10M
3 a)	Advantages of EVs → Absence of emissions, high efficiency, independence from fossil fuels, quiet & smooth operation (2M) Differences in infrastructure → use of gasoline tank – batteries (2M) → IC engine – Electric motor → Different transmission requirements	4M

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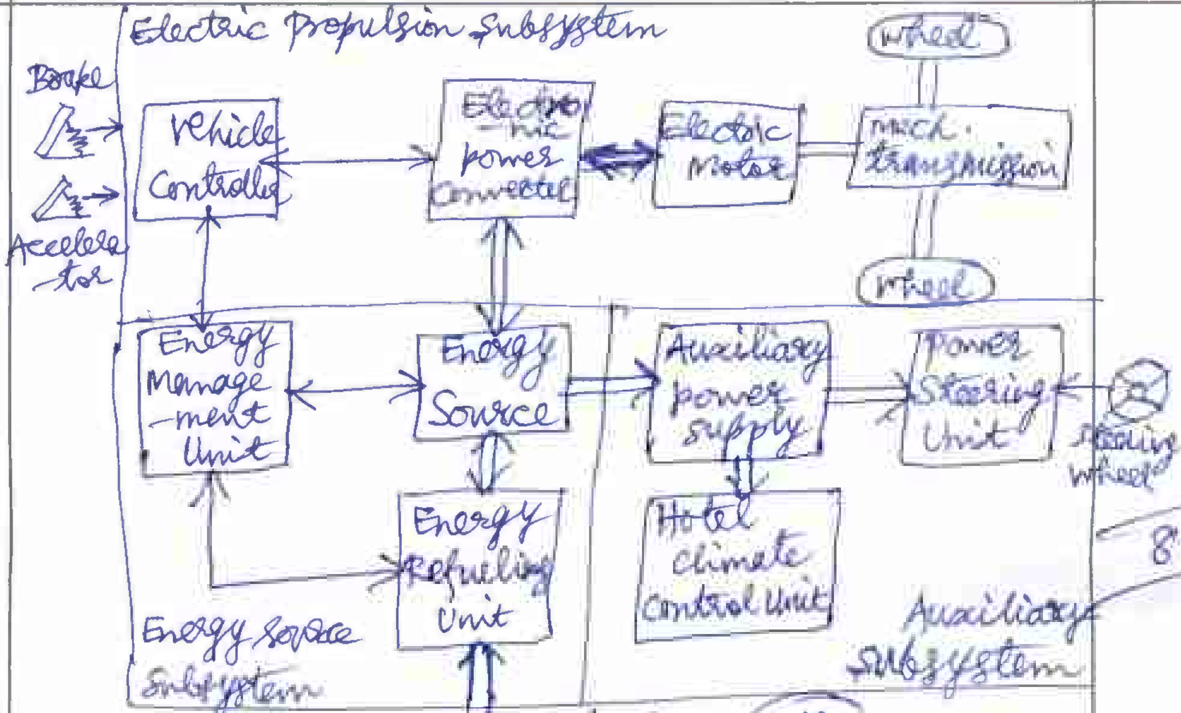
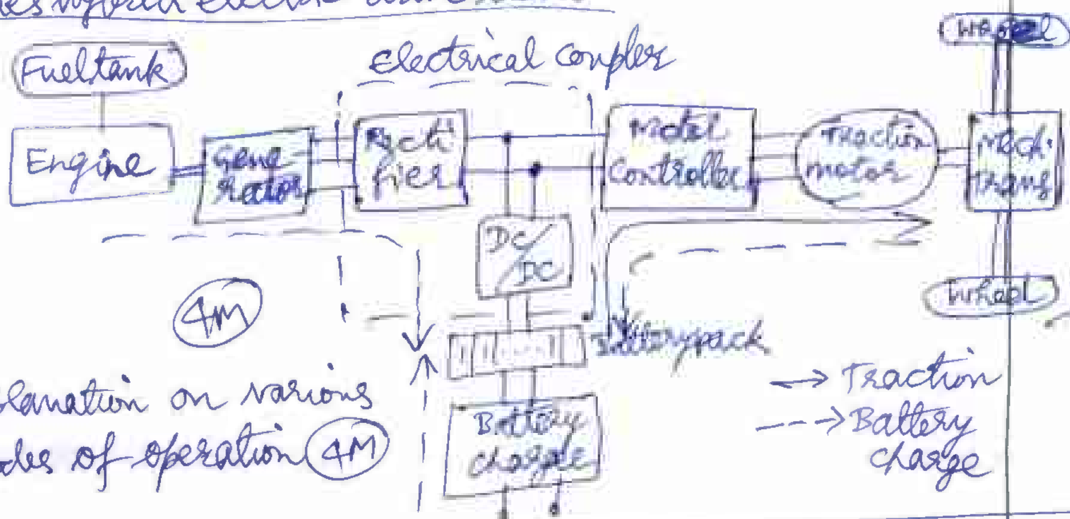
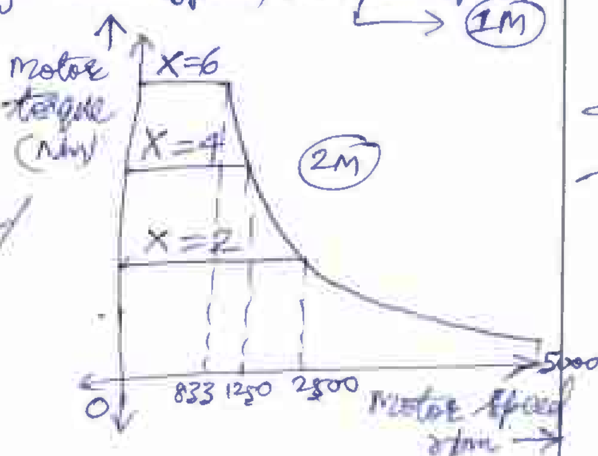
Subject Title : Electric vehicles Subject Code : 18EE752

Question Number	Solution	Marks Allocated
3) b)	 diagram — 4M Explanation on Electric propulsion subsystem, Energy source subsystem & Auxiliary subsystem → 4M	8M
3) c)	Series hybrid electric drive train  4M Explanation on various modes of operation 4M	8M
4) a)	Speed ratio (X) → Ratio of max. speed to base speed → 1M Explanation on speed-torque characteristics for constant power region / constant torque region. → 3M  2M	6M

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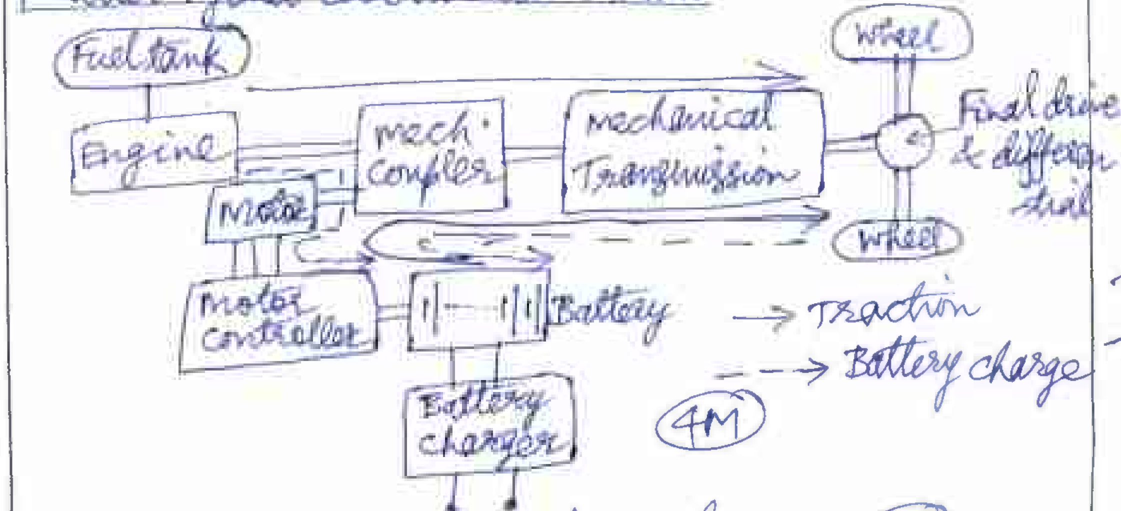
Subject Title : Electric vehicles **Subject Code :** 18EE752

Question Number	Solution	Marks Allocated

4) b) parallel hybrid electric drive train



(4M)

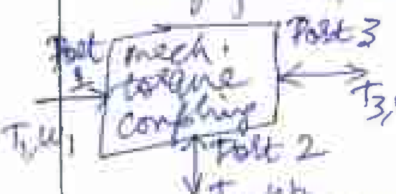
Explanation on operating modes ⟶ (4M)

8M

4) c) Types of mechanical coupling → torque coupling, → speed coupling (1M)

Torque coupling
- → Mech. coupler adds the torques of engine & motor together.
- → Then, it delivers the total torque to the driven wheels.
- → Engine & motor torques can be independently controlled
- → But, speeds of engine, motor & vehicle are linked by fixed relationship & cannot be independently controlled.

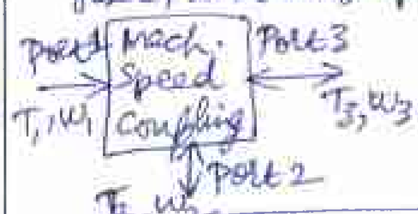
6M



$T_3 = K_1 T_1 + K_2 T_2$

$\omega_3 = \frac{\omega_1}{K_1} = \frac{\omega_2}{K_2}$ (3M)

Speed coupling
- → mech. coupler adds speeds of engine & motor together.
- → Then, it delivers the total speed to the driven wheels.
- → Engine & motor speeds can be independently controlled.
- → But, torques of engine, motor & vehicle are linked by fixed relationship & cannot be independently controlled.



$\omega_3 = \frac{1}{1+i_g}\omega_1 + \frac{i_g}{1+i_g}\omega_2 = k_1\omega_1 + k_2\omega_2$

$T_3 = \frac{T_1}{K_1} = \frac{T_2}{K_2}$ (2M)

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Question Number	Solution	Marks Allocated
5a)	Energy storage requirements:-	

→ Specific energy, → Specific power (2M)
→ Energy efficiency, → Maintenance requirement
→ Cost → Environmental adaptation
→ Friendliness & safety

Specific Energy → Energy capacity per unit battery weight.
→ Theoretical specific energy is max. energy that can be generated per unit total mass of cell reactants.

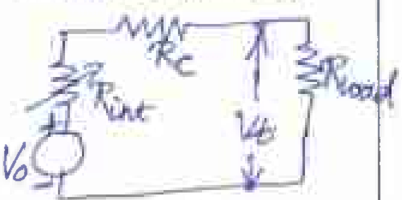
$$E_{spe} = \frac{-\Delta G}{3.6 \sum M_i} = \frac{-nFV_r}{3.6 \sum M_i} \text{ Wh/kg}$$ (2M)

8M

Specific power:→ Max power that the battery can produce in short period per unit battery weight.

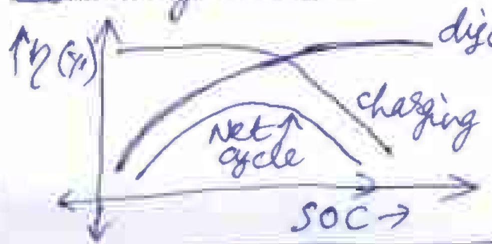
Max. power $P_{peak} = \frac{V_0^2}{2(R_c + R_{int})}$ (2M)

circuit model



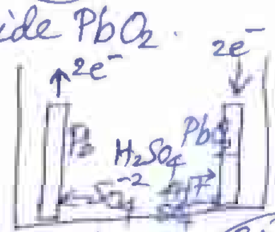
Energy efficiency
→ ratio of cell operating voltage to the thermodynamic voltage.
During discharging: $\eta = V/V_0$ and during charging: $\eta = V_0/V$

Efficiency curve



(2M)

5) b) Lead acid battery
Negative electrodes → porous lead Pb (2M)
Positive electrodes → porous lead oxide PbO_2.
Electrolyte → aqueous solution of sulfuric acid.



6M

During discharge mode:
At negative electrode → $Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$ (2M)
At positive electrode → $PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \rightarrow PbSO_4 + 2H_2O$.
overall → $Pb + PbO_2 + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$
During charging mode: At negative electrode; $PbSO_4 + 2e^- \rightarrow Pb + SO_4^{2-}$

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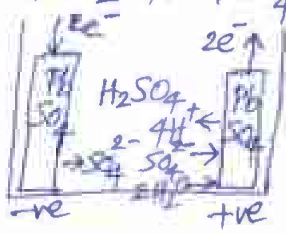
Question Number	Solution	Marks Allocated

At positive electrode; $PbSO_4 + 2H_2O \rightarrow PbO_2 + 4H^+ + SO_4^{2-} + 2e^-$

overall; $2PbSO_4 + 2H_2O \rightarrow Pb + PbO_2 + 2H_2SO_4$ (2M)



∴ overall reaction:

$$Pb + PbO_2 + 2H_2SO_4 \underset{\text{charge}}{\overset{\text{Discharge}}{\rightleftarrows}} 2PbSO_4 + 2H_2O.$$

5) c) Types of fuel cells

→ Proton Exchange Membrane fuel cells (PEMFCs)
→ Alkaline Fuel cells (AFCs)
→ phosphoric Acid Fuel cells (PAFCs)
→ Molten Carbonate Fuel Cells (MCFCs)
→ Solid oxide Fuel cells (SOFCs).
→ Direct Methanol Fuel Cells (DMFC)

(2M)

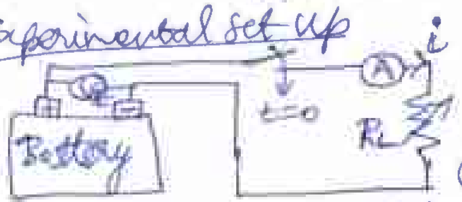
Explanation on Electrolyte used in each fuel cell → (4M)

Marks: 6M

6) a) Fractional Depletion Model of batteries

Constant current discharge approach

Experimental set up



(1M)

→ Battery is discharged at constant current for various R_L until V_t reaches V_{cut}. Then time taken in this experiment is taken as t_{cut}.

Peukert's empirical formula,

$$I^n t_{cut} = \lambda \quad \text{— (1)}$$

In log-log plot, I Vs t is linear

$$\Rightarrow \log(I) = -\tfrac{1}{n}\log(t_{cut}) + \tfrac{1}{n}\log\lambda$$

$$\therefore m = -\tfrac{1}{n} \Rightarrow n = -\tfrac{1}{m}. \quad (1M)$$

Then using eqn (1), λ can be found.

Then, $Q = I t_{cut} \Rightarrow t_{cut} = Q/I$.

power density approach

→ Peukert's eqn. is,

$$I^n \times Q/I = \lambda$$

$$\Rightarrow Q = \lambda / I^{n-1} \quad (1M)$$

Wkt, $SoD = \int i(\tau)d\tau$ & $DoD = \frac{SoD}{Q(i)}$

$$\Rightarrow d(DoD) = \frac{d(SOD)}{Q(i)} = \frac{i\,dt}{\lambda / i^{n-1}}$$

$$\Rightarrow d(DoD) = \frac{i^n}{\lambda}dt$$

$$\int d(DoD) = \int_{t_0}^{t} \frac{i^n}{\lambda}dt \quad (1M)$$

$$\Rightarrow DOD(t) = \int_{t_0}^{t} \frac{i^n}{\lambda}dt \times 100\,\%$$

Power density approach

Let $f_r(t)$ – fraction of available energy from 0 to t.

$$\Rightarrow df_r = dE/E_{ava} = \frac{dE/M_B}{E_{ava}/M_B}$$

$$\Rightarrow df_r = \frac{d(SE)}{SE_{ava}} \quad (1M)$$

Marks: 8M

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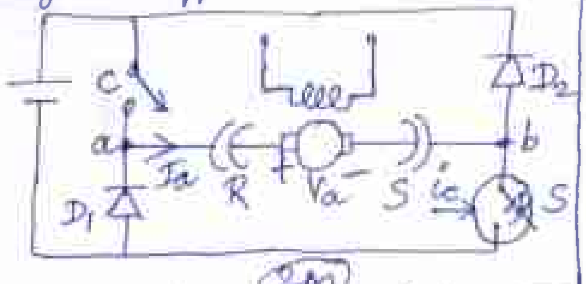
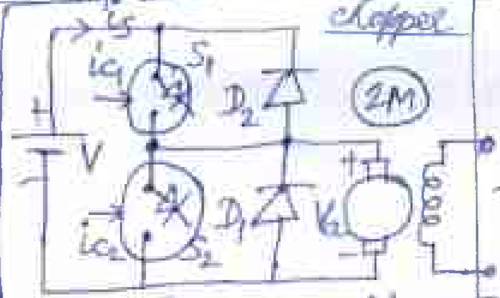
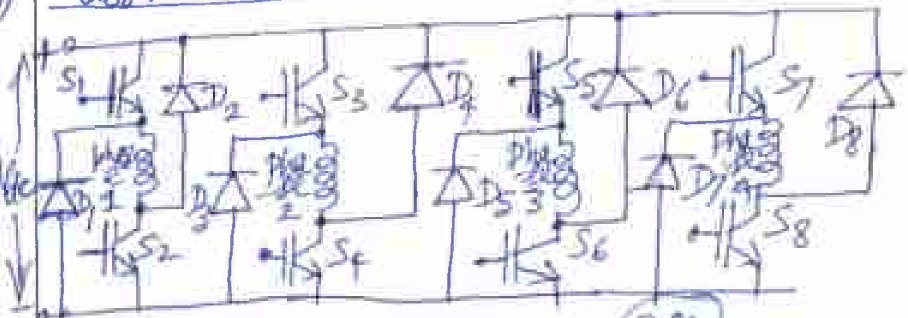
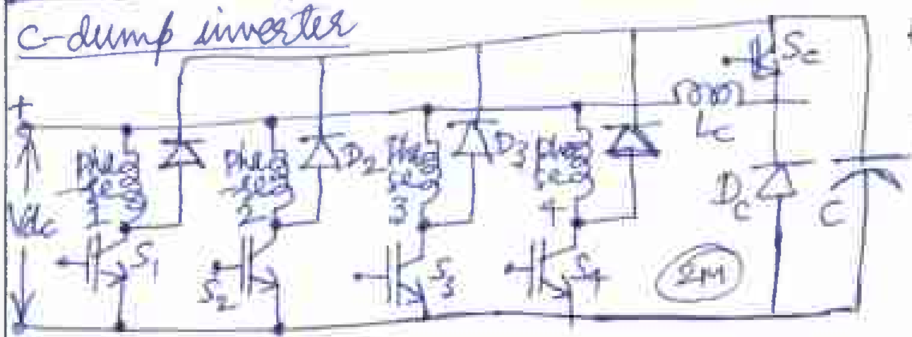
Question Number	Solution	Marks Allocated
	Energy provided $dE = p\,dt \Rightarrow d(SE) = (SP)\,dt$ (1M) specific energy available, $SE_{ava} = f(SP)$. Peukert's equation $\rightarrow (SP)^n \times SE_{ava} = \lambda \Rightarrow SE_{ava} = \frac{\lambda}{(SP)^n}$ (1M) $\therefore df_r = \frac{d(SE)}{SE_{ava}} = \frac{SP \times dt}{\lambda (SP)^n} = \frac{(SP)^{n+1}}{\lambda} dt$ $\Rightarrow \int df_r = \int_0^t \frac{(SP)^{n+1}}{\lambda} d\tau \Rightarrow f_r(t) = \int_0^t \frac{SP^{(n+1)}}{\lambda} d\tau$ (1M) Available energy from battery at time 't'. For 6(b) & 6(c) refer page 10	
7) a)	Single chopper with reverse switch  (2M) Explanation on operation → (3M) class-C two-quadrant chopper  (2M) Explanation on operation → (3M)	10M
7) b)	Classic Converter  (2M) Explanation on operation (2M) R-dump inverter  (2M) Explanation on the circuit → (1M) C-dump inverter  (2M) Explanation on the circuit → (1M)	10M

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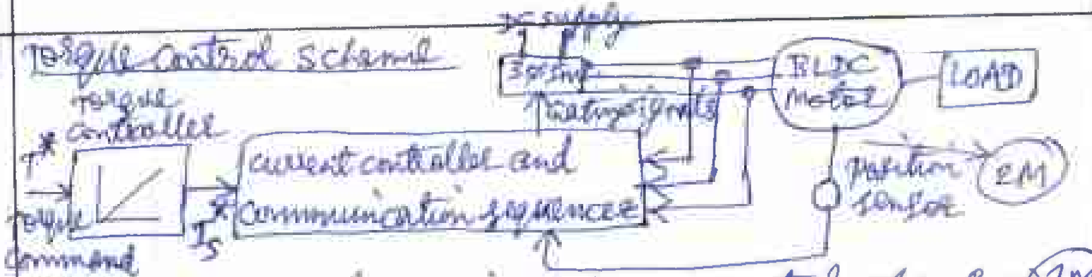
Subject Title : Electric Vehicles **Subject Code :** 18EE752

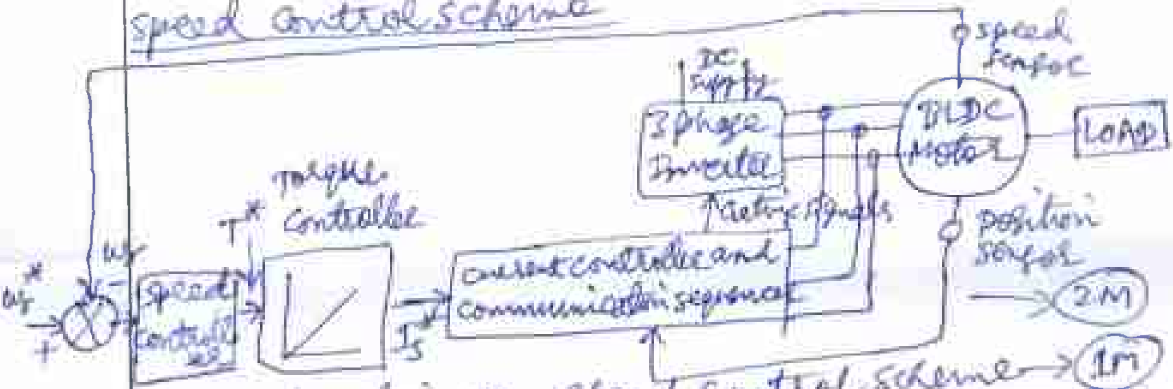
Question Number	Solution	Marks Allocated

8) a) Torque control scheme



Explanation on torque control scheme → 1M

speed control scheme



Explanation on speed control scheme → 1M

6M

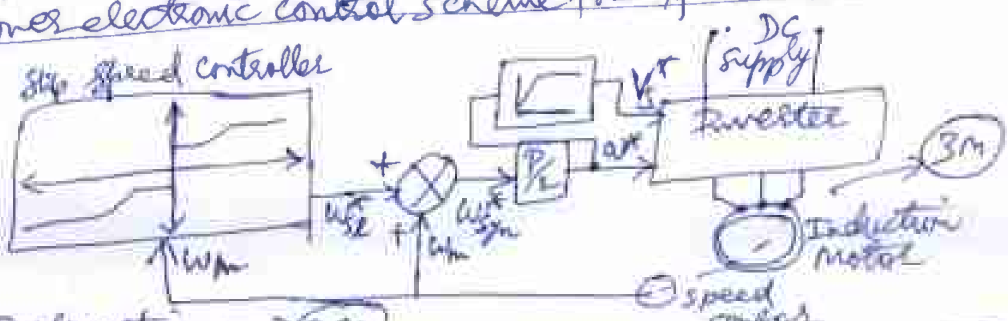
8) b) Advantages of BLDC motor → high efficiency, compactness, ease of control, ease of cooling, low maintenance, great longevity, reliability and low noise emissions → 2M

Disadvantages of BLDC motor → cost, limited constant power range, NO safety, magnet demagnetisation, NO high-speed capability, inverter failures in drives. → 2M

4M

8) c) Explanation on constant V/f control → 5M

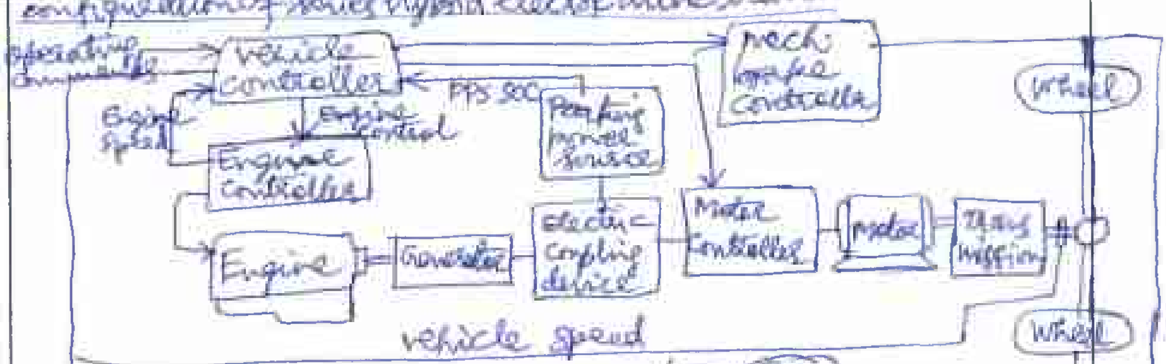
Power electronic control scheme for V/f control.



Explanation → 2M

10M

9) a) configuration of series hybrid electric drive train

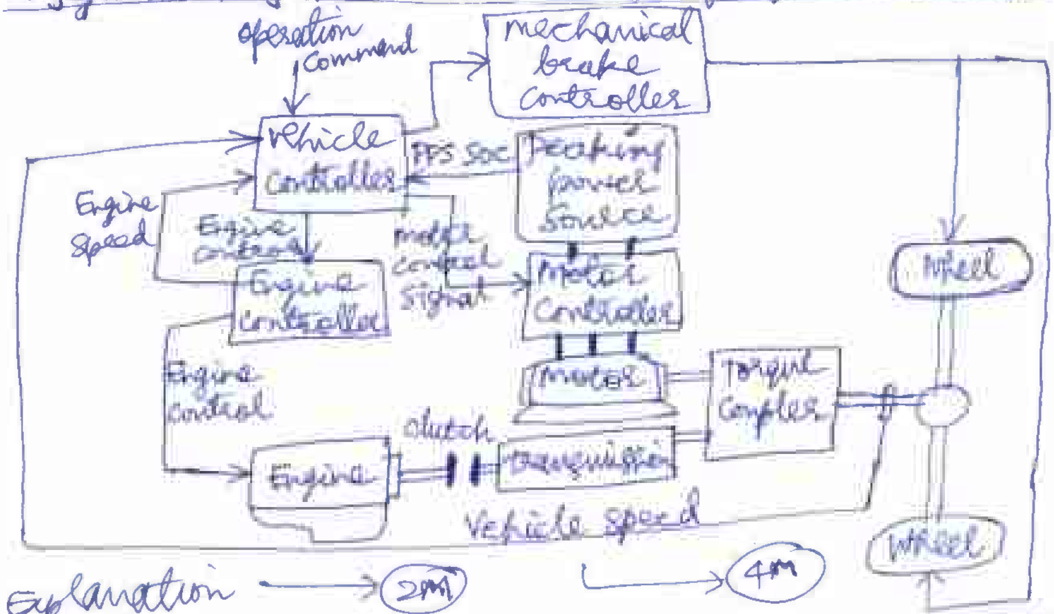


→ 5M

Subject Title : Electric vehicles

Subject Code : 18EE752

10/10

Question Number	Solution	Marks Allocated
	Operating patterns → Hybrid traction mode ($P_{demand} = P_{e/g} + P_{pps}$) → Peak power source-alone mode ($P_{demand} = P_{pps}$) → Engine/generator alone traction mode ($P_{demand} = P_{e/g}$) → PPS charging from engine/generator ($P_{demand} = P_{e/g} + P_{pps}$) → Regenerative braking mode. Explanation on each mode → (1M) each. (5M)	10M
9) b)	Explanation on Max. SOC-of-PPS control strategy → (5M) Explanation on Engine on-off or thermostat control strategy → (5M)	10M
10) a)	Configuration of parallel torque-coupling hybrid drive train  → (4M) Explanation → (2M)	6M
10) b)	Explanation on max-SOC-of-PPS control strategy → (5M) Explanation on Engine on-off control strategy → (4M) Explanation on constrained Engine on-off control strategy → (5M)	14M
6) b)	Li-ion battery : Lithium intercalated carbons (Li_xC) in form of graphite or coke as negative electrode. → Lithium metallic oxides ($Li_{1-x}M_yO_2$) as positive electrode → liquid organic solution or a solid polymer as electrolyte → Lithium nickel oxide ($LiNiO_2$)/Lithium cobalt oxide ($LiCoO_2$) as +ve electrode. Overall chemical reactions $LiC_6 + CoO_2 \underset{charge}{\overset{Discharge}{\rightleftharpoons}} C_6 + LiCoO_2$	8M
6) c)	Battery parameters → Battery capacity/Coulometric capacity/Ah → open-circuit voltage → Terminal voltage → Practical capacity → Discharge rate → State-of-charge (SOC) → State-of-Discharge (SOD)/Depth of Discharge (DOD) → Battery energy → Thermodynamic voltage	4M