CBCS SCHEME

USN | | | | | | | | | | |

21EE752

Seventh Semester B.E./B.Tech. Degree Examination, Dec.2024/Jan.2025

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. With an example graph of roadway on the fixed co-ordinate system, explain the following terms used in roadway fundamentals :
   i) Roadway position vector
   ii) Tangential road way length
   iii) Roadway percent grade. **(10 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 $0 \leq x_F \leq 2$ miles, where x_F and y_F are given in feet.
   i) Plot the roadway
   ii) Find $\beta(x_f)$ calculate the percent grade at $x_f = 1$ mile
   iii) Calculate tangential length. **(10 Marks)**

OR

2 a. Discuss in brief the dynamics of vehicle motion with relevant dynamic modeling equations and block diagram. **(07 Marks)**

b. Discuss in brief the concept of maximum gradability. **(05 Marks)**

c. An electric vehicle has the following parameter values : m = 800 kg, $C_D = 0.2$, $A_F = 2.2\ m^2$, $C_0 = 0.008$, $C_1 = 1.6 \times 10 - 6\ s^2/m^2$. The density of air p = 1.8 kg/m^3 and acceleration due to gravity g = 9.81 m/s^2. The vehicle is on level road. It accelerates from 0 to 65 mph in 10 seconds, such that its velocity profile is given by,
   $V(t) = 0.29055\ t^2$ for $0 \leq t \leq 10$seconds
   Calculate :
   i) $F_{TR}(t)$ for $0 \leq t \leq 10$seconds
   ii) $P_{TR}(t)$ for $0 \leq t \leq 10$seconds
   iii) Energy loss due to non –conservative forces
   iv) Δe_{TR}. **(08 Marks)**

Module-2

3 a. With a neat diagram, discuss about the conceptual illustration of general EV configuration and list out the variety of possible EV configurations with relevant diagrams due to variation in propulsion design and energy source. **(10 Marks)**

b. Discuss with relevant graphs,
   i) Traction motor characteristics
   ii) Tractive effect and transmission requirement. **(10 Marks)**

OR

4 a. List out the different architecture of hybrid electric drive trains, also draw the diagram to show conceptual illustrate of hybrid electric derive train. **(04 Marks)**

b. With a neat diagram, explain the series hybrid electric drive train. **(06 Marks)**

c. With a neat diagram, discuss the general configuration of parallel hybrid electric drive train and also draw the diagrams showing the two shaft configurations. **(10 Marks)**

Module-3

5 a. List out any ten battery parameters and briefly discuss about any two of them. **(10 Marks)**

b. With a neat diagram of cell charge and discharge operation of lead-acid battery, discuss in brief the operating principle with relevant chemical reaction equations. **(10 Marks)**

OR

6 a. With a neat diagram, discuss the working principle of Lithium – ion (Li – ion) battery along with chemical reactions and two advantages. **(10 Marks)**

b. List out the any four types of fuel cell and mention the electrolyte used in each of them. **(04 Marks)**

c. Find the curve fitting constants 'n' and 'λ' for Peukert's equation for the two measurements available form a constant current discharge experiment of a battery.

i) $(t_1, I_1) = (10, 18)$

ii) $(t_2, I_2) = (1, 110)$. **(06 Marks)**

Module-4

7 a. Discuss the two quadrant operation of chopper with respect to the following control schemes of DC motor in electric vehicles.

i) Single chopper with a reverse switch

ii) Class –C two quadrant chopper **(10 Marks)**

b. Discuss in brief the following topologies used for SRM drive in electric vehicles :

i) Classic converter

ii) R – dump inverter

iii) C – dump inverter. **(10 Marks)**

OR

8 a. Discuss the following control schemes used for BLDC motor drive in electric vehicles.

i) Torque control scheme

ii) Speed control scheme. **(10 Marks)**

b. Discuss the constant v/f control as applicable to induction motor drive for EVs. **(05 Marks)**

c. With a neat diagram (block diagram) explain the power electronic control scheme for constant V/f control. **(05 Marks)**

Module-5

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

b. For the vehicles with different mission requirements, discuss the various control strategies employed in a series hybrid electric drive train. **(10 Marks)**

OR

10 a. Discuss in detail the parallel torque coupling hybrid drive train with a neat diagram. **(08 Marks)**

b. Discuss in brief the following strategies employed in 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. **(12 Marks)**

* * * * *

Solutions

1.a) With **an example graph of roadway on the fixed co-ordinate system, explain the following terms used in roadway fundamentals:**

i) Roadway position vector

ii) Tangential roadway length

iii) Roadway percent grade.

The two-dimensional roadway can be described as $y_F = f(x_F)$. The *roadway position vector* $\bar{r}(x_F)$ between two points a and b along the horizontal direction is

$$\bar{r}(x_F) = x_F \bar{i}_F + f(x_F)\bar{j}_F \quad \text{for} \quad a \le x_F \le b.$$

The direction of motion and distance traversed by the vehicle is easier to express in terms of the *tangent vector* of the roadway position vector given as

$$\bar{T}(x_F) = \frac{d\bar{r}}{dx_F} = \bar{i}_F + \frac{df}{dx_F}\bar{j}_F$$

The distance norm of the tangent vector $\left\|\bar{T}(x_F)\right\|$ is

$$\left\|\bar{T}(x_F)\right\| = \sqrt{1 + \left[\frac{df}{dx_F}\right]^2}$$

The *tangential roadway length* s is the distance traversed along the roadway. Mathematically, s is the arc length of $y_F = f(x_F)$ over $a \le x_F \le b$. Therefore,

$$s = \int_a^b \left\|\bar{T}(x_F)\right\| dx_F.$$

The roadway percent grade can be described as a function of the roadway as

$$\beta(x_F) = \tan^{-1}\left[\frac{df(x_F)}{dx_F}\right].$$

The *average roadway percent grade* is the vertical rise per 100 horizontal distance of roadway with both distances expressed in the same unit. The angle β of the roadway associated with the slope or grade is the angle between the tangent vector and the horizontal axis x_F as shown in Figure 2.2. If Δy is the vertical rise in meters, then

$$\%\ \text{grade} = \frac{\Delta y}{100\ \text{m}} 100\% = \Delta y\%.$$

The tangent of the slope angle is, $\tan\beta = \dfrac{\Delta y}{100\,\text{m}}$.

The percent grade or β is greater than zero when the vehicle is on an upward slope and is less than zero when the vehicle is going downhill.

1.b) A straight roadway has a profile in XF - YF plane given by, f(xF) =3.9√XF for 0 ≤ xp ≤ 2 miles, where XF and yF are given in feet. i) Plot the roadway ii) Find ẞ(x) calculate the percent grade at x= 1 mile i) Calculate tangential length.

Ans. (b) $\tan^{-1}\dfrac{1.95}{\sqrt{x_F}}$; (c) 2.68% and (d) 10,580 ft.

2.a) Discuss in brief the dynamics of vehicle motion with relevant dynamic modeling equations and block diagram.

The tractive force is the force supplied by the electric motor in an EV and by the combination of electric motor and internal combustion engine in a HEV to overcome the road load. The dynamic equation of motion in the tangential direction is given by

$$k_m m \frac{dv_{xT}}{dt} = F_{TR} - F_{RL} \tag{2.5}$$

where k_m is the rotational inertia coefficient to compensate for the apparent increase in the vehicle's mass due to the on-board rotating mass. Typical value of k_m is between 1.08 and 1.1, and it is dimensionless. Additional explanation on rotational inertia appears in Section 2.7.4. $\dfrac{dv_{xT}}{dt}$ is the acceleration of the vehicle.

The dynamic equations can be represented in the state space format for simulation of an EV or a HEV system. The motion described by Equation 2.5 is the fundamental relationship required for dynamic simulation of the vehicle system. v_{xT} is one of the state variables of the vehicle dynamical system. The second equation needed for modeling and simulation is the velocity equation where either s or x_F can be used as the state variable. The slope of the roadway β will be an input to the simulation model, which may be given in terms of the tangential roadway distance s as $\beta = \beta(s)$ or in terms of the horizontal distance as $\beta = \beta(x_F)$. If β is given in terms of s, then the second state variable equation is

$$\frac{ds}{dt} = v_{xT}. \tag{2.6}$$

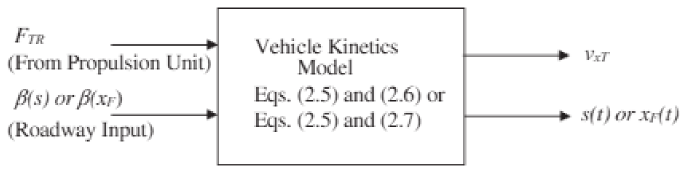


FIGURE 2.9 Modeling of vehicle kinetics and roadway.

If β is given in terms of x_F, then the second state variable equation is

$$\frac{dx_F}{dt} = \frac{v_{xT}}{\sqrt{1+\left[\dfrac{df}{dx_F}\right]^2}}. \tag{2.7}$$

2.b) Discuss in brief the concept of maximum gradability.

The maximum grade that a vehicle will be able to overcome with the maximum force available from the propulsion unit is an important design criterion as well as performance measure. The vehicle is expected to move forward very slowly when climbing a steep slope, and hence, we can make the following assumptions for maximum gradability:

1. The vehicle moves very slowly $\Rightarrow v \cong 0$.
2. F_{AD} and F_{roll} are negligible.
3. The vehicle is not accelerating, i.e., $dv/dt = 0$.
4. F_{TR} is the maximum tractive force delivered by motor (or motors) at near zero speed.

At near stall condition, under the above assumptions,

$$\Sigma F = 0 \Rightarrow F_{TR} - F_{gxT} = 0 \Rightarrow F_{TR} = mg\sin\beta.$$

Therefore, $\sin\beta = \frac{F_{TR}}{mg}$. The maximum percent grade is

$$\text{Max.\% grade} = 100\tan\beta$$

$$\Rightarrow \text{Max.\% grade} = \frac{100F_{TR}}{\sqrt{(mg)^2 - F_{TR}^2}} \tag{2.10}$$

The force diagram for the maximum gradability condition is shown in Figure 2.12.

2.c) An electric vehicle has the following parameter values : m = 800 kg, Cp = 0.2, AF = 2.2 m^2, Co = 0.008, C_1 = 1.6 x 10- 6 s^2/m^2. The density of air p = 1.8 kg/m^3 and acceleration due to gravity g = 9.81 m/s^2. The vehicle is on level road. It accelerates from 0 to 65 mph in 10 seconds, such that its velocity profile is given by, V(t) = 0.29055 t2 for 0 ≤ t≤ 10seconds Calculate: i) FTR(t) for 0 ≤ t≤ 10seconds ii) PTR(t) for 0 ≤t ≤ 10seconds iii) Energy loss due to non -conservative forces Important Note: 1. On completing answers, your compulsorily diagonal draw cross lines on the remaining blank pages. 2. Any revealing identification, of

to appeal evaluator /or and equations written eg, 42+8 50, = will be treated malpractice. as Детг.

a.

From the force balance equation,

$$F_{TR} - F_{AD} - F_{roll} = m\frac{dv}{dt}$$

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

$$= 464.88t + 0.02192\,t^4 + 62.78 \text{ N.}$$

b.

The instantaneous power is

$$P_{TR}(t) = F_{TR}(t) \times v(t)$$

$$= 135.07t^3 + 0.00637t^6 + 18.24t^2 \text{ W.}$$

c.

The energy lost due to nonconservative forces

$$E_{loss} = \int_0^{10} v(F_{AD} + F_{roll})\,dt = \int_0^{10} 0.29055t^2(0.0219t^4 + 62.78)\,dt$$

$$= 15{,}180 \text{ J.}$$

d.

The kinetic energy of the vehicle is

$$\Delta KE = \frac{1}{2}m\left[v(10)^2 - v(0)^2\right] = 337{,}677 \text{ J}$$

Therefore, the change in tractive energy is

$$\Delta e_{TR} = 15{,}180 + 337{,}677$$

$$= 352{,}857 \text{ J.}$$

3.a) With a neat diagram, discuss about the conceptual illustration of general EV configuration and list out the variety of possible EV configurations with relevant diagrams due to variation in propulsion design and energy source.

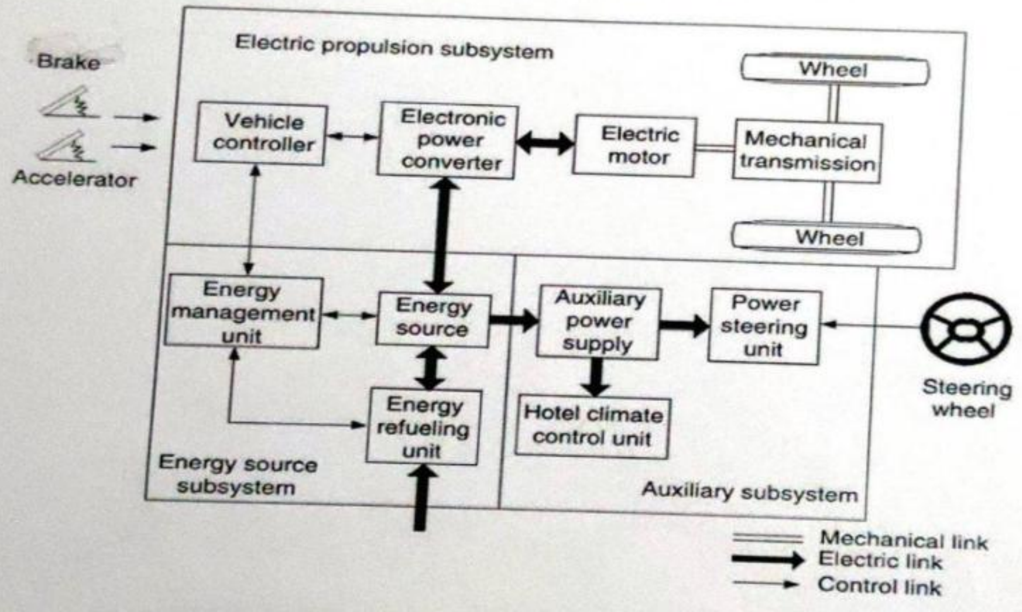
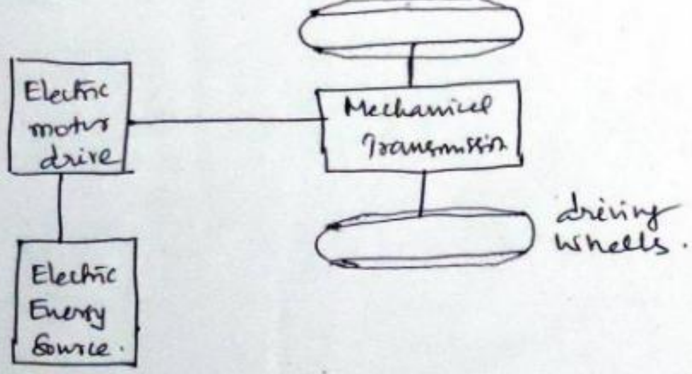


Fig. 2a: Conceptual illustration of general EV configuration

⇒ previously, EV mainly converted from the existing ICEV by replacing the internal combustion engine and fuel tank with an electric motor drive and battery pack while retaining all other components as shown in Fig. 1



(i) Primary electric vehicle power train.

⇒ Drawbacks such as

- its heavy weight
- lower flexibility
- Performance degradation

3.b) Discuss with relevant graphs,

i) Traction motor characteristics ii) Tractive effect and transmission requirement.

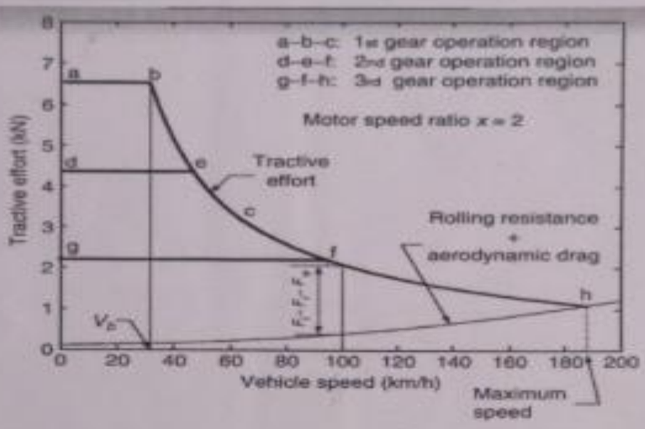


Fig. 2.4: Tractive effort vs. vehicle speed with a traction motor of x = 2 and three-gear transmission

Above, fig. shows tractive effort of an EV, along with the vehicle speed with a traction motor of $x = 2$ and 3 gear transmission.

1st gear → a - b - c
2nd gear → d - e - f
3rd gear → g - f - h

Below fig. shows tractive effort of an EV, with traction motor of $x = 4$ and a two gear transmission.

Rolling resistance → the force resisting the motion when body rolls on a surface.

Aerodynamic drag → the force of an object that resists its motion through a air is called aerodynamic drag.

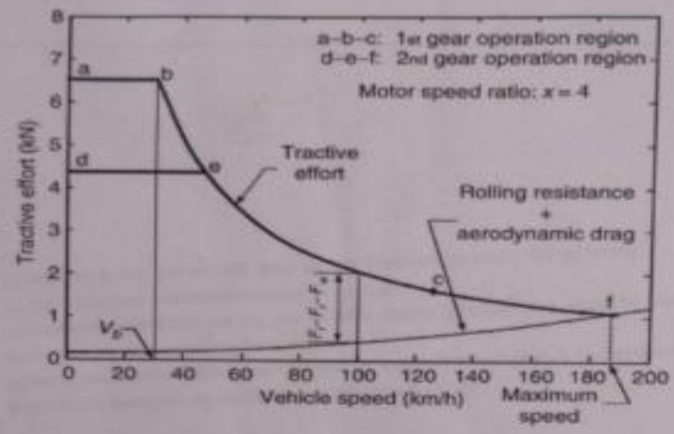


Fig. 2.5: Tractive effort vs. vehicle speed with a traction motor of x=4 and two-gear transmission

Above fig shows of x=4, and a two gear transmission

First gear covers → a – b – c

Second gear covers → d – e – f

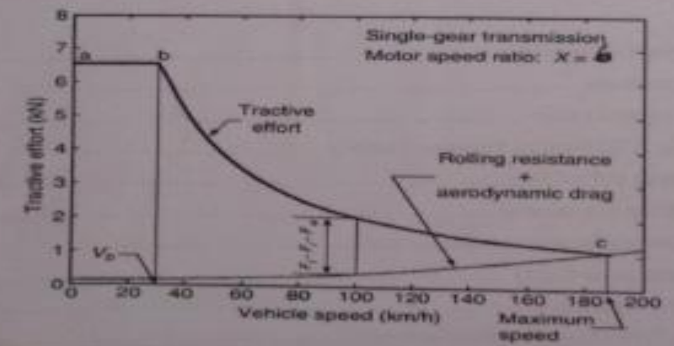


Fig: Tractive effort Vs Vehicle Speed with a traction motor x=6 and ~~two~~ single gear transmission.

4.a) List out the different architecture of hybrid electric drive trains, also draw the diagram to show conceptual illustrate of hybrid electric derive train.

HEV's System and Configuration.

BEV Present Status:

- It has higher energy efficiency w.r.t HEV/ICE
- Allows diversification of energy sources.
- Load equalization of power system.
- Zero emission locally and minimum globally.
- Quick operation
- Short driving range, high initial cost, charging etc

Hybridization in EV's

- Hybrid energy sources in BEVs → only electric
- Hybrid drivetrains in HEVs. → ICE engine based

Hybrid Electric Vehicle:

→ Extend the range of EV many times

→ offers rapid refueling

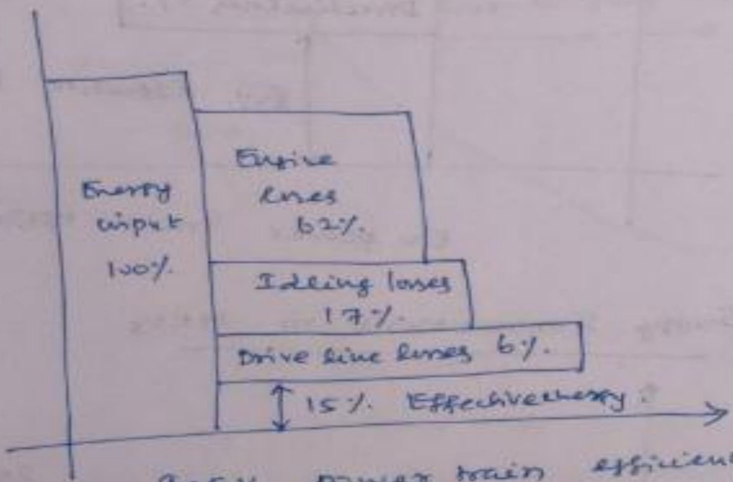
→ Not a zero emission vehicle, but lesser than ICEV.

→ IC Engine Efficiency is higher.

→ lower fuel consumption

→ Complex system.

Vehicular Power train Efficiency in EVs and ICEVs



ICEV power train efficiency.

⇒ major loss as heat energy.

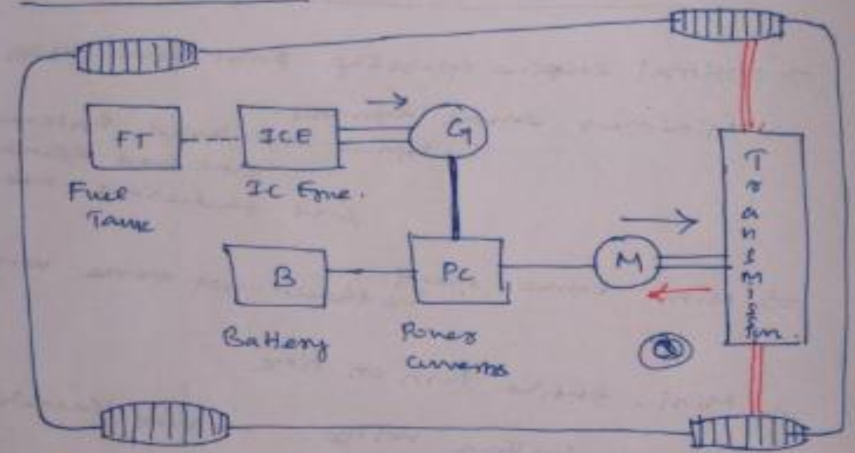
⇒ ICE engine left idling - 17%.

⇒ Drive line - mech loss.

4.b) With a neat diagram, explain the series hybrid electric drive train.

I. Series Hybrid EV: (Electrically coupling).

Front wheels



Rear wheels

Electrical link

Hydraulic link

Mechanical link

G - generator.

Propulsion - device is electrical

=> Simple to make

=> Few draw backs - need more mechanical systems.

=> Difficulty for high acceleration.

=> Sizing - high.

=> ~~~~

=> Start up / Normal driving / Acceleration

=> Full system is active.

=> Lighter load - part of it used to charge the battery.

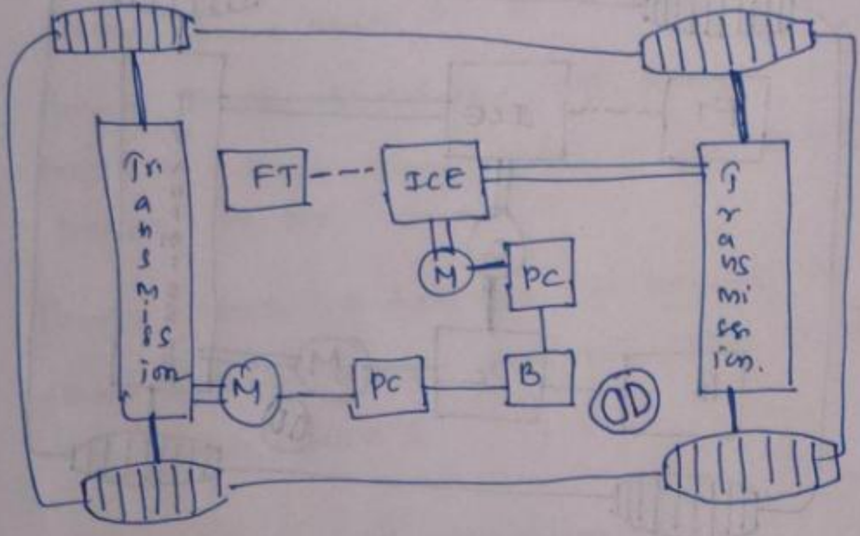
=> Deceleration / Braking - energy recovered from wheels

=> Battery charging at standstill - battery charging -

4.c) With a neat diagram, discuss the general configuration of parallel hybrid electric drive and also draw the diagrams showing the two shaft configurations.

IV Complex Hybrid EV [Mechanical and Electrical coupling]

→ Front engine rear electric

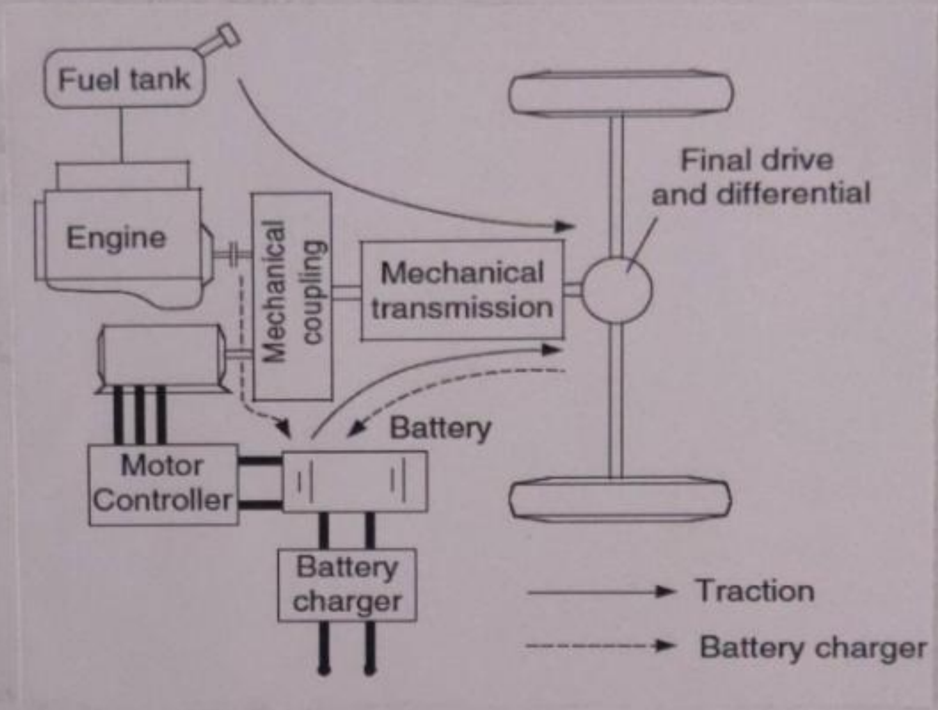


=> 2 Motor & 1 ICE engine → 3 propulsion devices

=> High T

=> dual axle transmission

Parallel Hybrid Electric Drive Train:



⇒ All the possible operating modes in the series hybrid drive train are still effective.

5.a) List out any ten battery parameters and briefly discuss about any two of them.

i) INTERNAL VOLTAGE

ii) TERMINAL VOLTAGE

iii) BATTERY CAPACITY

iv) discharge Rate

v) SOC

vi)DOD

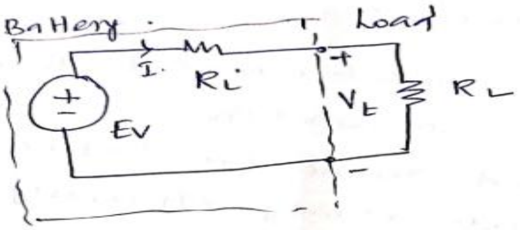
vii)SOH

viii) Energy efficiency

ix) Battery energy

x) Energy Density

(i) <u>Internal Voltage:</u> (Ev)



Ev − battery internal voltage appears at the battery terminals as open circuit voltage when there is no load connected to it.

OCV − depends on
- state of charge of the battery.
- temperature
- past discharge | charge history.

(iv) <u>charge | discharge rate:</u> C Rate continuation ~~~~

<u>Ex.</u>

For a 15 kwh battery

⇒ 1 C charge | discharge rate means pumping in or taking out power at 15 kW.

↳ can charge (or) drain the battery fully (SoC 0% and 100%) in 1 hour.

⇒ 2 C Rate implies push in | pull out power at twice the battery capacity rate, that is at 30 kW.

↳ battery will charge | discharge in 30 minutes.

5.b) With a neat diagram of cell charge and discharge operation of lead-acid battery, discuss (10 Marks) brief the operating principle with relevant chemical reaction equations

The lead-acid batteries have been the most popular choice of batteries for electric vehicles during the initial development stages. The lead-acid battery has a long history that dates back to the middle of the nineteenth century and is currently a very mature technology. The first lead-acid battery was produced as early as in 1859. In the early 1980s, over 100 million lead-acid batteries were produced per year. The long existence of the lead acid battery is due to

- Relatively low cost
- Easy availability of raw materials (lead, sulfur)
- Ease of manufacture
- Favorable electromechanical characteristics

Chemical Reaction for Discharging

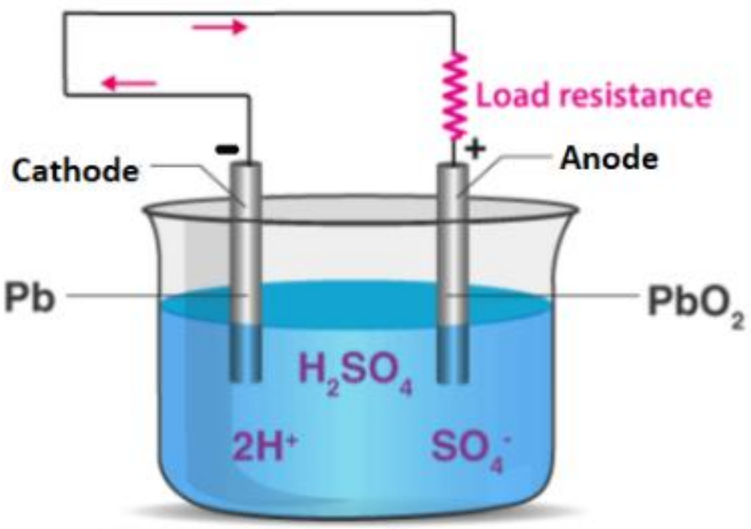
When the battery is discharged, it acts as a galvanic cell and the following chemical reaction occurs.

Negative:

$Pb(s) + HSO_4^- + H_2O(l) \rightarrow 2e^- + PbSO_4(s) + H_3O^+(aq)$ (oxidation)

Positive:

$PbO_2(s) + HSO_4^-(aq) + 3H_3O^+(aq) + 2e^- \rightarrow PbSO_4(s) + 5H_2O(l)$ (reduction)



Lead-Acid Battery Discharging

Chemical Reaction for Recharging

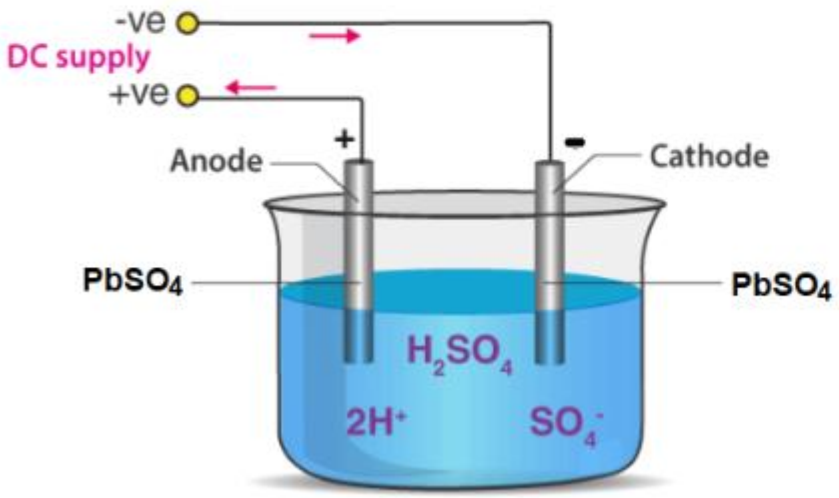
The chemical reaction that takes place when the lead-acid battery is recharging can be found below.

Negative:

$2e^- + PbSO_4(s) + H_3O^+(aq) \rightarrow Pb(s) + HSO_4^- + H2O(l)$ (reduction)

Positive:

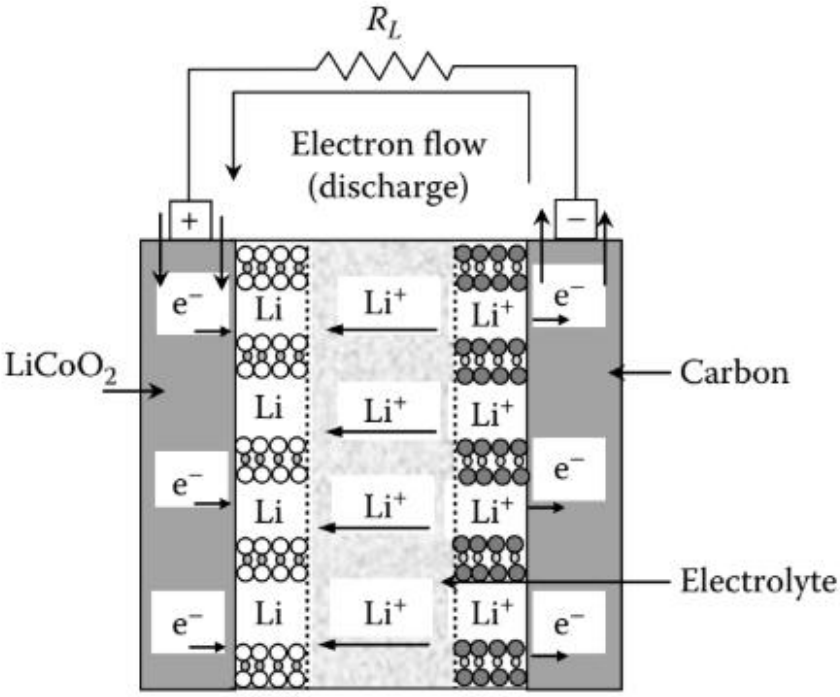
$PbSO_4(s) + 5H_2O(l) \rightarrow PbO_2(s) + HSO_4^-(aq) + 3H_3O^+(aq) + 2e^-$ (oxidation)



Lead-Acid Battery charging

6.a) With a neat diagram, discuss the working principle of Lithium – ion (Li – ion) battery along with chemical reactions and two advantages.

The lithium metal has high electrochemical reduction potential relative to that of hydrogen (3.045V) and the lowest atomic mass (6.94), which shows promise for a battery of 3V cell potential when combined with a suitable positive electrode. The interest in secondary lithium cells soared soon after the advent of lithium primary cells in the 1970s, but the major difficulty was the highly reactive nature of the lithium metal with moisture that restricted the use of liquid electrolytes. The discovery in late 1970s by researchers at Oxford University that lithium can be intercalated (absorbed) into the crystal lattice of cobalt or nickel to form LiCoO2 or LiNiO2 paved the way toward the development of Li-ion batteries



At the negative electrode,

$$Li_xC_6 \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} 6C + xLi^+ + xe^- \quad \text{where } 0 < x < 1$$

At the positive electrode,

$$xLi^+ + xe^- + Li_{(1-x)}CoO_2 \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} LiCoO_2$$

During cell charge operation, the lithium ions move in the opposite direction from the positive electrode to the negative electrode. The nominal cell voltage for a Li-ion battery is 3.6 V, which is equivalent to three NiMH or NiCd battery cells.

6.b) List out the any four types of fuel cell and mention the electrolyte used in each of them.

Fuel Cell Types

Fuel Cell Variety	Fuel	Electrolyte
Phosphoric acid	H_2, reformate (LNG, methanol)	Phosphoric acid
Alkaline	H_2	Potassium hydroxide solution
Proton exchange membrane	H_2, reformate (LNG, methanol)	Polymer ion exchange film
Direct methanol	Methanol, ethanol	Solid polymer
Molten carbonate	H_2, CO (coal gas, LNG, methanol)	Carbonate
Solid oxide	H_2, CO (coal gas, LNG, methanol)	Yttria-stabilized zirconia

7.a) Discuss the two quadrant operation of chopper with respect to the following control schemes of DC motor inin electric vehicles. i) Single chopper with a reverse switch ii) Class-C two quadrant chopper

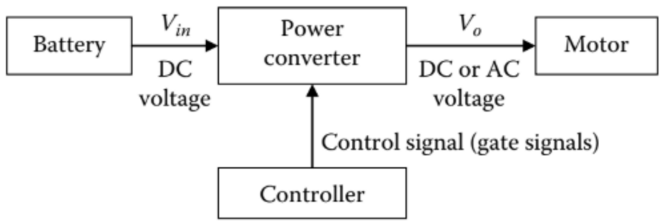
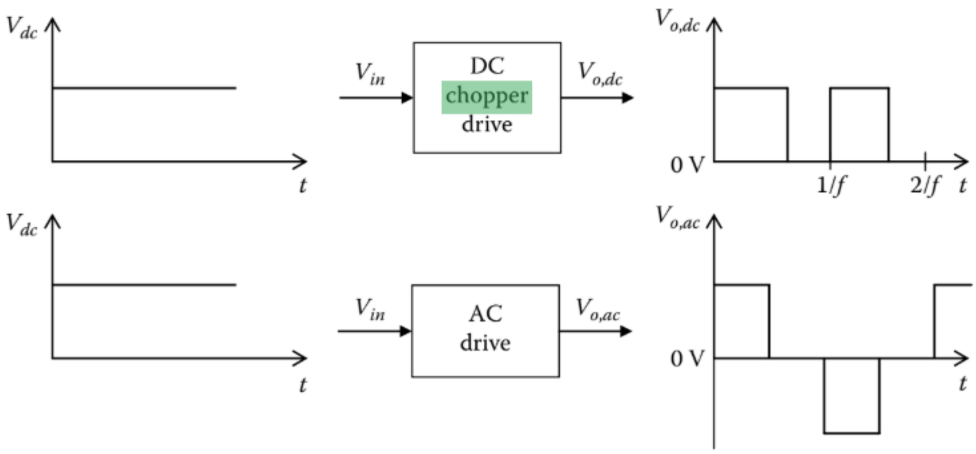
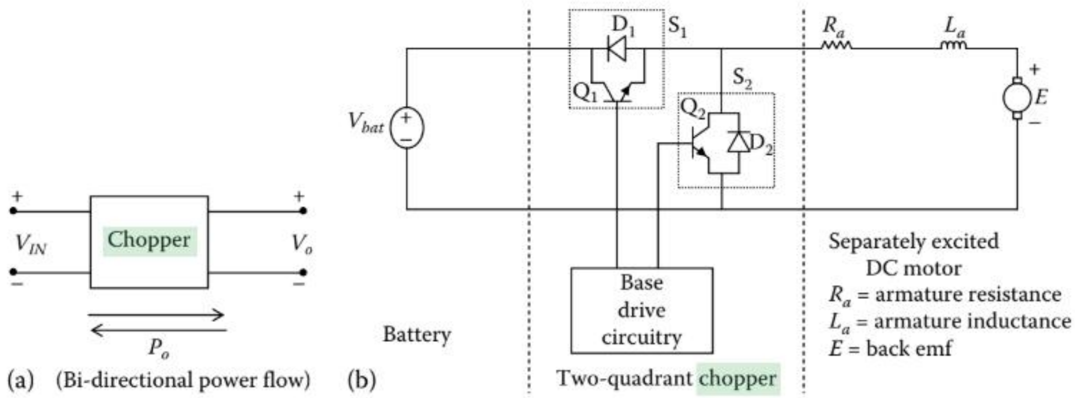


FIGURE 8.1
Block diagram of a motor drive.



The two-quadrant DC chopper allows bidirectional current and power flow with unidirectional voltage supply. The schematic of a two-quadrant chopper is shown in Figure 8.3. The motor current i_0 is inductive current, and therefore cannot change instantaneously. The transistor Q_1 and diode D_1



7.b) Discuss in brief the following topologies used for in electric vehicles :i) Classic converter ii) R-dump inverter iii) C-dump inverter. CK

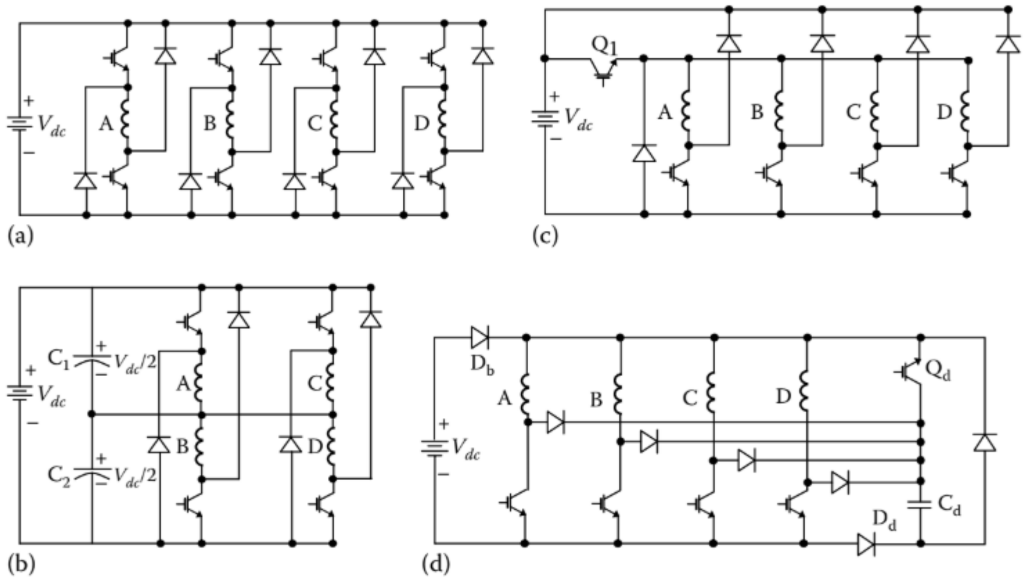
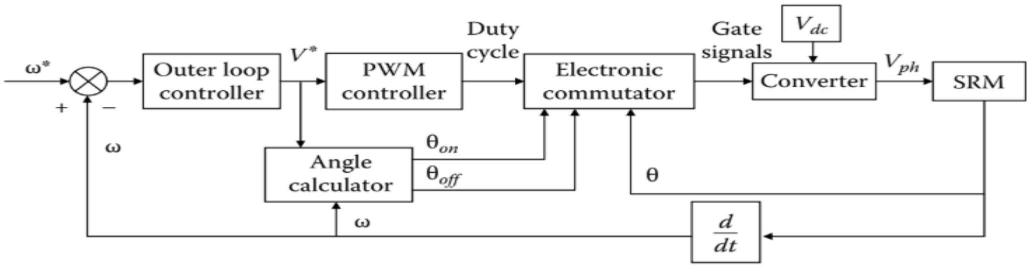


FIGURE 8.34
Converter topologies for SRM: (a) classic bridge power converter; (b) split-capacitor converter; (c) Miller converter, and (d) energy-efficient converter.

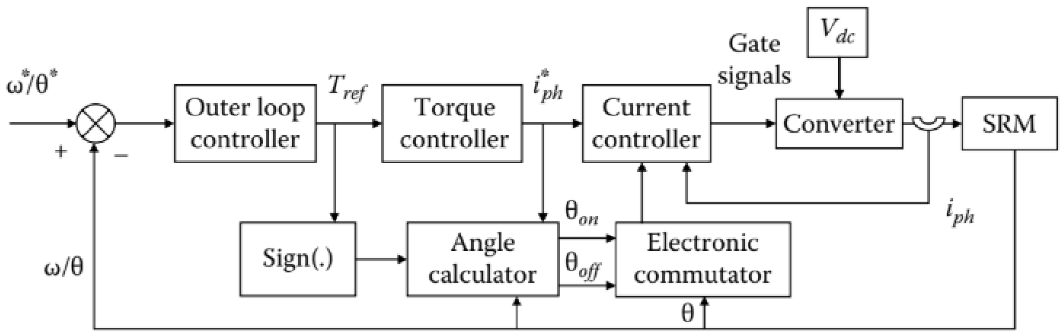
Converters with reduced number of switches are typically less fault-tolerant compared with the bridge converter. The ability to survive component or motor phase failure is a highly attractive feature for high-reliability applications. On the other hand, in low-voltage applications, the voltage drop in two switches can be a significant percentage of the total bus voltage, which may not be affordable. Among other factors to be considered in selecting a drive circuit are cost, complexity in control, number of passive components, number of floating drivers required, and so on. The drive converter must be chosen to serve the particular needs of an application.

8. a) Discuss the following control schemes used for BLDC motor drive in electric vehicles. i) Torque control scheme ii) Speed control scheme.

ii) Speed control scheme.



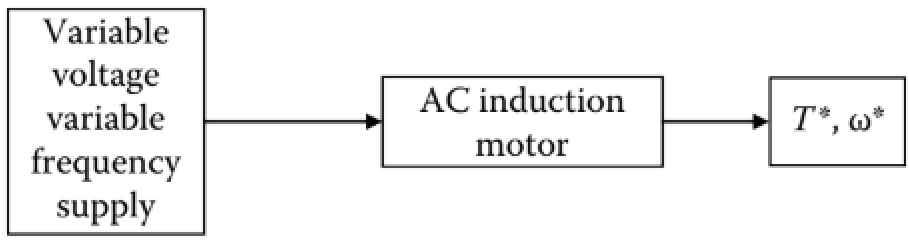
i) Torque control scheme

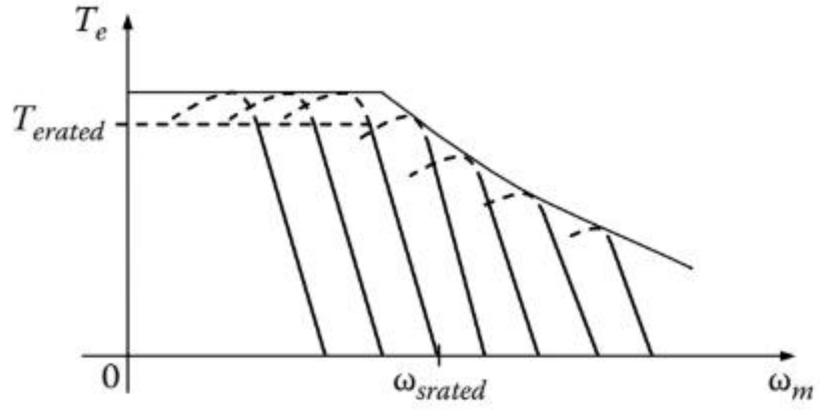


The machines that use magnets to produce air-gap magnetic flux instead of field coils as in DC commutator machines or magnetizing component of stator current as in induction machines are called *PM machines*. This configuration eliminates the rotor copper loss as well as the need for maintenance of the field exciting circuit. The PM machines can be broadly classified into two categories:

- PM synchronous machines (PMSM): These machines have uniformly rotating stator field as in induction machines. The induced waveforms are sinusoidal and hence *dq* transformation and vector control are possible.
- PM trapezoidal or brushless DC machines (PM BLDC): The induced voltages in these machines are trapezoidal in nature; the phase currents are rectangular or square wave in nature. These PM machines are also known as *square wave* or *electronically commutated machines*. The stator field is switched in discrete steps with square wave pulses.

B b) Discuss the constant v/f control as applicable to induction motor drive for EVs.

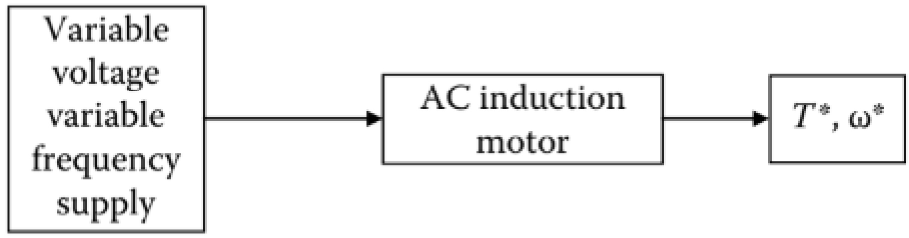




The speed of an induction motor can be controlled in two ways by varying the stator terminal voltage and by varying the stator frequency. Changing the terminal voltage changes the torque output of the machine, as is evident from Equation 6.42. Note that changing the applied voltage does not change the slip for maximum torque. The speed control through changing the

applied frequency is based on the frequency and synchronous speed relation $\omega_e = 4\pi f/p$; changing f changes ω_e. Figures 6.28 and 6.29 show the variations in torque–speed characteristics with changes in voltage and frequency, respectively. What is needed to drive the induction motor is a power electronics converter that will convert the available constant voltage into a variable voltage, variable frequency output according to the command torque and speed. The top-level block diagram of such a drive system is shown in Figure 6.30. The first generation controllers of induction motor drives used in electric vehicles employed slip control (constant V/Hz control) using a table of slip versus torque. The performance of such a drive for vehicle applications is very poor, since the concept of V/Hz control is based on steady-state equivalent circuit of the machine. The dynamic performance of the machine improves significantly using vector control. The *dq*-axes transformation theory for induction motors pertaining to vector control theory will be covered in Chapter 9, which discusses high-performance AC motor control methods.

8.c) Discuss the constant v/f control as applicable to induction motor drive for EVs. (05 Marks) c. With a neat diagram (block diagram) explain the power electronic control scheme for constant V/f control.



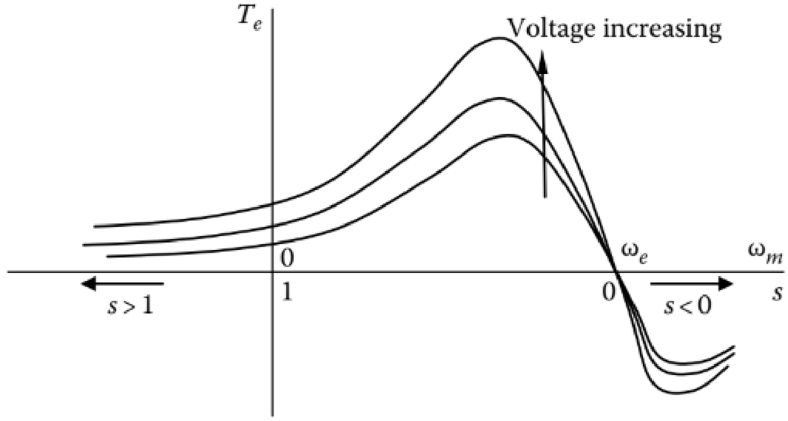
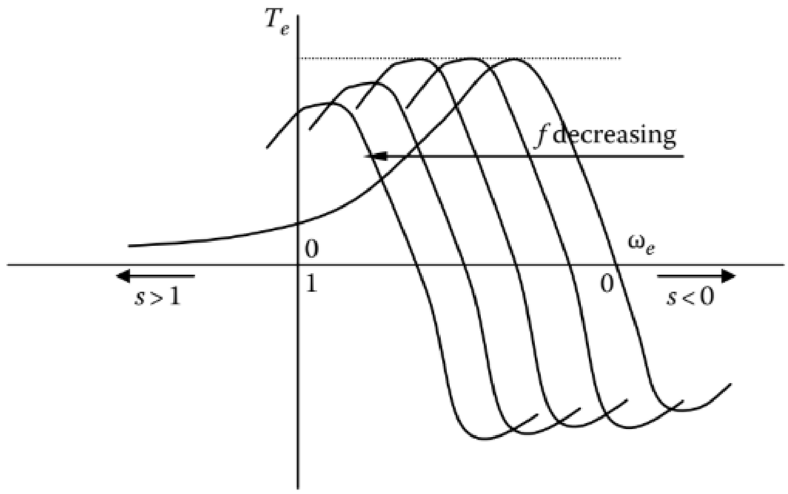


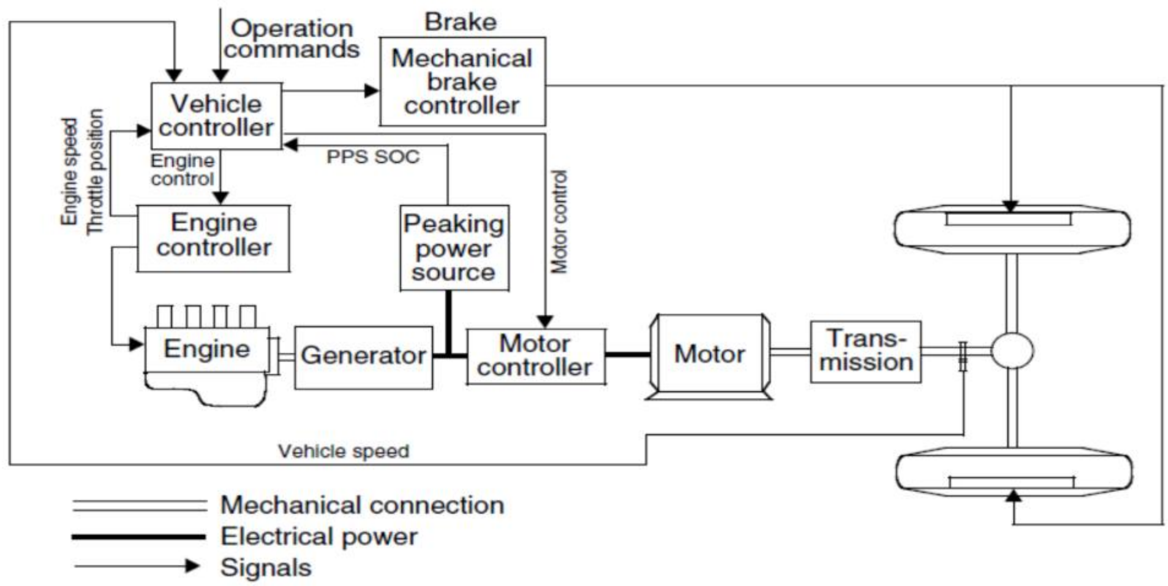
FIGURE 6.28
Torque–speed profile at different voltages with fixed supply frequency.



applied frequency is based on the frequency and synchronous speed relation $\omega_e = 4\pi f/p$; changing f changes ω_e. Figures 6.28 and 6.29 show the variations in torque–speed characteristics with changes in voltage and frequency, respectively. What is needed to drive the induction motor is a power electronics converter that will convert the available constant voltage into a variable voltage, variable frequency output according to the command torque and speed. The top-level block diagram of such a drive system is shown in Figure 6.30. The first generation controllers of induction motor drives used in electric vehicles employed slip control (constant V/Hz control) using a table of slip versus torque. The performance of such a drive for vehicle applications is very poor, since the concept of V/Hz control is based on steady-state equivalent circuit of the machine. The dynamic performance of the machine improves significantly using vector control. The *dq*-axes transformation theory for induction motors pertaining to vector control theory will be covered in Chapter 9, which discusses high-performance AC motor control methods.

9.a) Discuss the various operating patterns of series hybrid electric derive train for its optimal operation and draw a typical series hybrid electric drive train configuration.

CONFIGURATION OF A TYPICAL SERIES HYBRID ELECTRIC DRIVE TRAIN



OPERATING PATTERNS

The engine should be controlled in such a way that it always operates in its optimal operation region, where fuel consumption and emissions of the engine are minimized

The drive train has several operating modes, which can be used selectively according to the driving condition and desire of the driver the following operating modes are available

- **Hybrid traction mode**
- **Peak Power Source-Alone Traction Mode**
- **Engine/Generator-Alone Traction Mode**
- **PPS Charging from the Engine/Generator**
- **Regenerative Braking Mode**

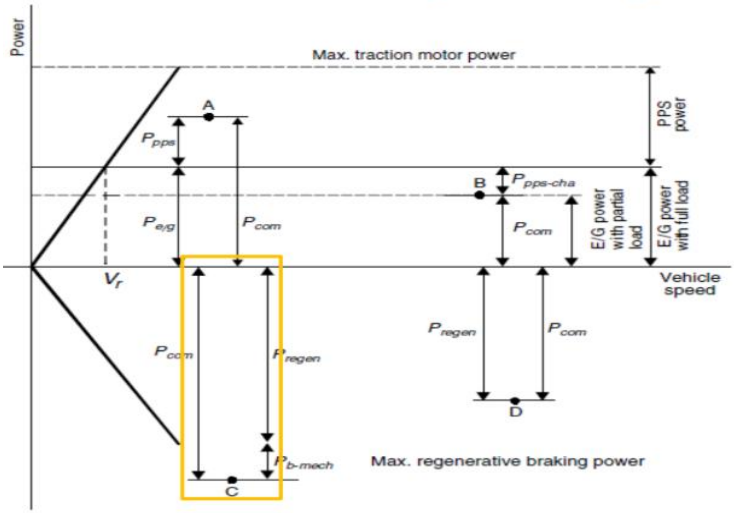
OPERATING PATTERNS

The vehicle controller commands the operation of each component according to the traction power (torque) command from the driver, the feedback from each of the components, and also the drive train and the preset control strategy. The control objectives are to

- **Meet the power demand of the driver**
- **Operate each component with optimal efficiency**
- **Recapture braking energy as much as possible**
- **Maintain the state-of-charge (SOC) of the PPS in a preset window.**

9.b) For the vehicles with different mission requirements, discuss the various control strategies employed in a series hybrid electric drive train.

Maximum State-of-charge Of Peaking Power Source Control Strategy



A — Hybrid traction mode
P_{com} — Commanded power
P_{pps} — Power of the peaking power source
$P_{e/g}$ — Power of engine/generator

B — Engine/generator-alone traction mode or PPS charging mode
$P_{pps\text{-}cha}$ — PPS charging power

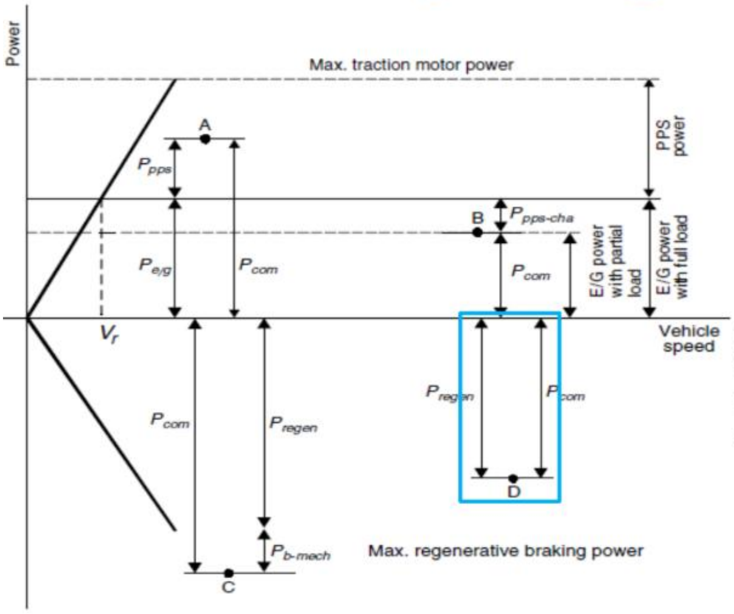
C — Hybrid braking mode
P_{regen} — Regenerative braking power
$P_{b\text{-}mech}$ — Mechanical braking power

D — Regenerative braking mode

Point C represents the commanded braking power that is greater than the braking power that the motor can produce (maximum regenerative braking power).

In this case, the hybrid braking mode is used, in which the electric motor produces its maximum braking power and the mechanical braking system produces the remaining braking power.

Maximum State-of-charge Of Peaking Power Source Control Strategy



A — Hybrid traction mode
P_{com} — Commanded power
P_{pps} — Power of the peaking power source
$P_{e/g}$ — Power of engine/generator

B — Engine/generator-alone traction mode or PPS charging mode
$P_{pps\text{-}cha}$ — PPS charging power

C — Hybrid braking mode
P_{regen} — Regenerative braking power
$P_{b\text{-}mech}$ — Mechanical braking power

D — Regenerative braking mode

Point D represents the commanded braking power that is less than the maximum braking power that the motor can produce. In this case, only regenerative braking is used.

10.a) Discuss in detail the parallel torque coupling hybrid drive train with a neat diagram.

Control Strategies of Parallel Hybrid Drive Train

The available operation modes in a parallel hybrid drive train are

(1) engine-alone traction,

(2) electric-alone traction,

(3) hybrid traction (engine plus motor),

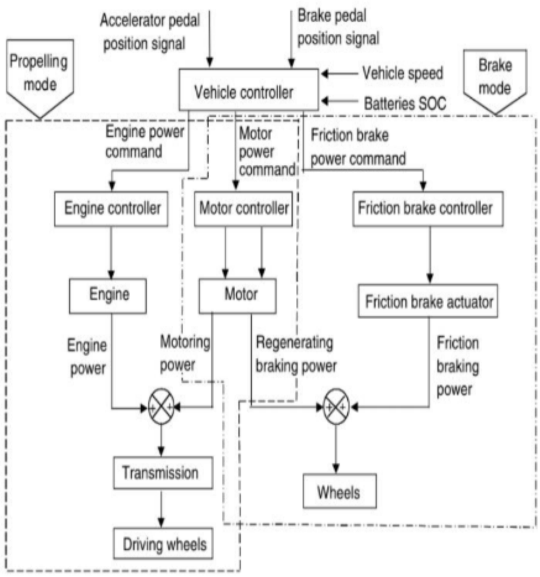
(4) regenerative braking, and

(5) peaking power source (PPS) charging from the engine.

During operation, the proper operation modes should be used so as

- To meet the traction torque requirement,
- achieve high overall efficiency,
- maintain a reasonable level of PPS SOC, and
- recover braking energy as much as possible.

- It consists of a vehicle controller, engine controller, electric motor controller, and mechanical brake controller.
- The vehicle controller is in the highest position. It collects data from the driver and all the components, such as desired torque, vehicle speed, PPS SOC, engine speed and throttle position, electric motor speed, etc.
- Based on these data, component characteristics, and preset control strategy, the vehicle controller gives its control signals to each component controller/local controller.
- Each local controller controls the operation of the corresponding component to meet the requirements of the drive train.
- The vehicle controller plays a central role in the operation of the drive train. The vehicle controller should fulfill various operation modes — according to the drive condition and the data collected from components and the driver's command — and should give the correct control command to each component controller.
- Hence, the preset control strategy is the key to the optimum success of the operation of the drive train.

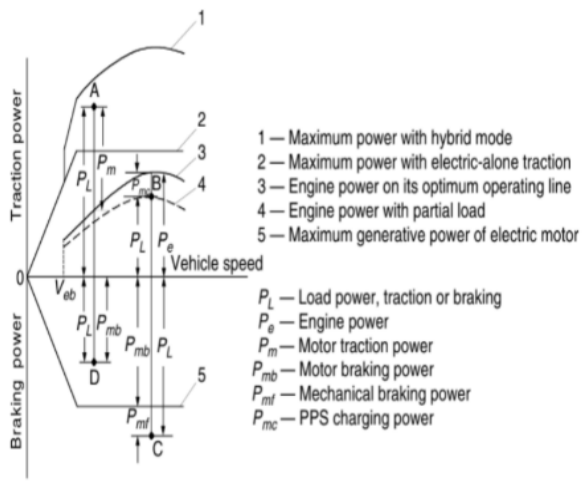


10.b) Discuss in brief the following strategies employed in parallel hybrid electric drive train : i) Max SOC – of – PPS control strategy ii) Engine on -off control strategy iii) Constrained engine on -off control strategy.

Maximum State-of-Charge of Peaking Power Source (Max. SOC-of-PPS) Control Strategy

- When a vehicle is operating in a stop-and-go driving pattern, the PPS must deliver its power to the drive train frequently.
- Consequently, the PPS tends to be discharged quickly. In this case, maintaining a high SOC in the PPS is necessary to ensure vehicle performance.
- Thus, the maximum SOC of the PPS control strategy may be the proper option.

- The maximum power curves for hybrid traction (engine plus electric motor), engine-alone traction, electric motor-alone traction, and regenerative braking are plotted against vehicle speed. Power demands in different conditions are also plotted, represented by points A, B, C, and D.
- The operation modes of the drive train are explained below:
    1. Motor-alone propelling mode
    2. Hybrid propelling mode
    3. PPS charge mode
    4. Engine-alone propelling mode
    5. Regenerative-alone brake mode
    6. Hybrid braking mode



1. Motor-alone propelling mode:

The vehicle speed is less than a preset value Veb, which is considered to be the bottom line of the vehicle speed below which the engine cannot operate steadily. In this case, the electric motor alone delivers its power to the driven wheels, while the engine is shut down
or idling. The engine power, electric traction power, and the PPS discharge power can be written as

$$P_e = 0,$$

$$P_m = \frac{P_L}{\eta_{t,m}},$$

$$P_{pps\text{-}d} = \frac{P_m}{\eta_m},$$

where
Pe is the engine power output,
PL is the load power demand on the drive wheels,
ηt,m is the transmission efficiency from the motor to the driven wheels,
Pm is the power output of the electric motor,
Ppps-d is the PPS discharge power, and
ηm is the motor efficiency.

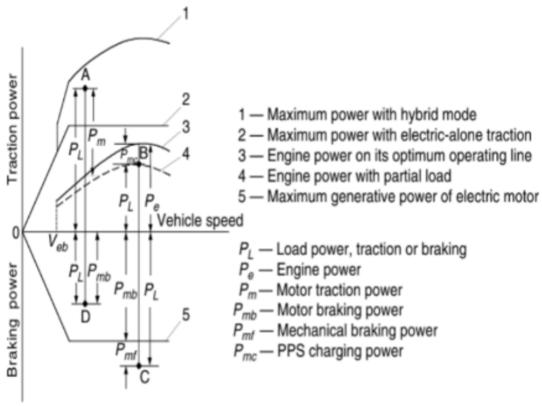
4. Engine-alone propelling mode:

- When the load power demand is less than the power that the engine can produce while operating on its optimum operation line, and the PPS SOC has reached its top line, the engine-alone propelling mode is used. In this case, the electric system is shut down, and the engine is operated to supply the power that meets the load power demand.
- The power output curve of the engine with a partial load is represented by the dashed line.
- The engine power, electric power, and battery power can be expressed by

$$P_e = \frac{P_L}{\eta_{t,e}},$$

$$P_m = 0,$$

$$P_{pps} = 0.$$



Engine Turn-On and Turn-Off (Engine-On–Off) Control Strategy

- Similar to that used in a series hybrid drive train, the engine turn-on and turn-off control strategy may be used in some operation conditions with low speed and low acceleration. In an engine-on–off control strategy, the operation of the engine is controlled by the SOC of PPS.
- In the engine-on period, the control is Max. SOC-of-PPS strategy. When the SOC of the PPS reaches its top line, the engine is turned off and the vehicle is propelled only by the electric motor.
- When the SOC of the PPS reaches its bottom line, the engine is turned on and the control again goes into Max. SOC-of-PPS.

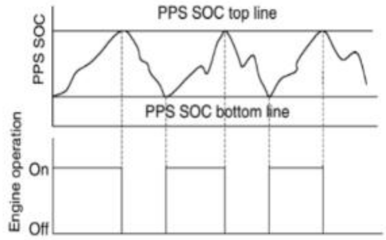


Fig. Illustration of engine-on–off control strategy