CMR INSTITUTE OF TECHNOLOGY		USN							
Internal Assessment Test –II									
Sub:	Electric Vehicle							Code:	18EE752
Date:	21/12/2021	Duration:	90 mins	Max Marks:	50	Sem:	7th	Branch:	ME/CS/IS/EC/CV
Answer Any FIVE FULL Questions									

		Marks	OBE	
			CO	RBT
1 (a)	Write a short note on Tractive effort in normal driving.	[5]	CO2	L2
1 (b)	Discuss the performance of Electric vehicle using speed-power characteristics.	[5]	CO2	L2
2	Discuss Electric vehicle performance in terms of maximum cruising speed, gradeability and acceleration.	[10]	CO2	L2
3	Discuss about Architectures of Hybrid Electric Drive Trains	[10]	CO2	L2
4	Discuss about following battery parameters (a)Battery Capacity (b) State of Charge (SOC) (c)Discharge Rate (C Rate) (d)Depth of Discharge (DOD) (e)Internal Voltage	[10]	CO3	L2

PTO

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PTO

5	List out types of batteries used in EV’S and explain about all of them in brief.	[10]	CO3	L2
6	List different types of electric circuit battery models and explain in detail about All of them.	[10]	CO3	L2
7	List out different types of fuel cells and explain in detail about Proton exchange membrane fuel cell.	[10]	CO3	L2
8	Discuss about concept of hybrid electric drive trains.	[10]	CO2	L2

CCI CI

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8	Discuss about concept of hybrid electric drive trains.	[10]	CO2	L2

CCI CI

IAT-2 Solutions

1 (a)

2.3 Tractive Effort in Normal Driving:

During normal driving conditions of the electric Vehicle the maximum capabilities are rarely considered. During most of the operation time, the power train operates with partial load.
Actual tractive effort (power) and vehicle speed vary widely with operating conditions, such as

- Acceleration or deceleration
- Uphill or downhill motion, etc.

These variations are associated with the traffic environment as well as the type of vehicles. City and highway traffic conditions vary greatly, as do the different.
City and highway traffic conditions vary significantly based on the missions of the vehicles, such as a

- Universal passenger car
- Vehicles with regular operation routes and schedules.

It is difficult to describe the tractive effort and vehicle speed variations in all actual traffic environments accurately and quantitatively. However, some representative drive cycles (driving schedules) have been developed to emulate typical traffic environments.
The EPA Federal Test Procedure, commonly known as FTP-75 for the city driving cycle, are a series of tests defined by the US Environmental Protection Agency (EPA) to measure tailpipe emissions and fuel economy of passenger cars (excluding light trucks and heavy-duty vehicles).

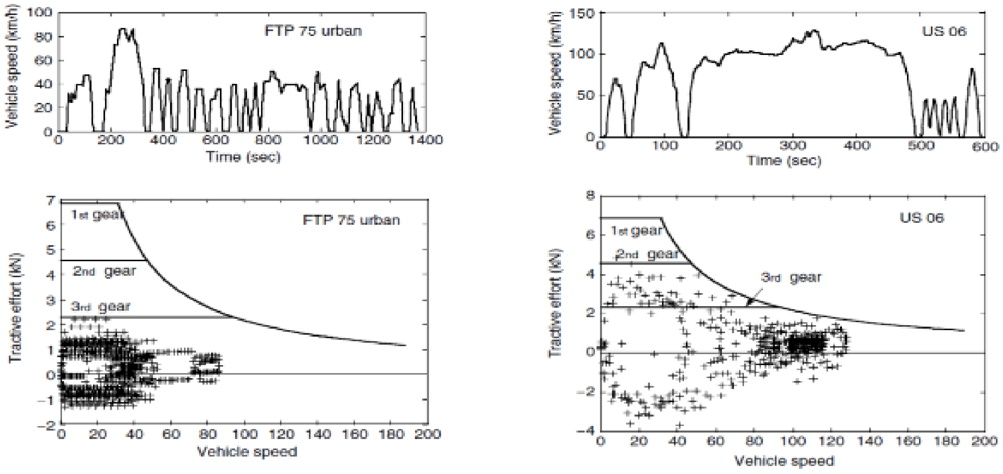
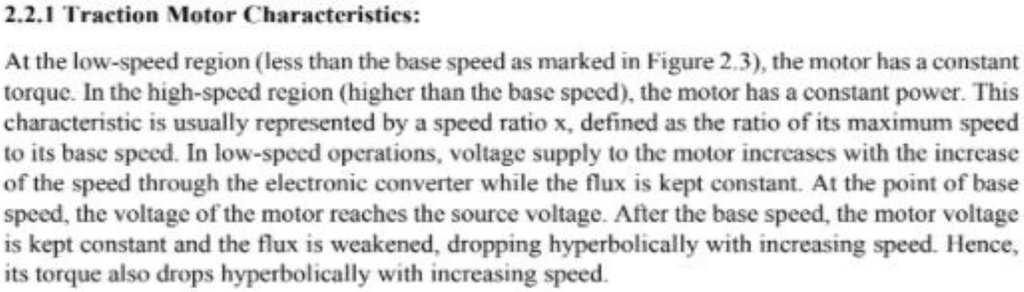


Fig. 2.7: Urban and Highway Environment

2.5M for description

2.5M for Graphs

1 (b)



2.2.1 Traction Motor Characteristics:

At the low-speed region (less than the base speed as marked in Figure 2.3), the motor has a constant torque. In the high-speed region (higher than the base speed), the motor has a constant power. This characteristic is usually represented by a speed ratio x, defined as the ratio of its maximum speed to its base speed. In low-speed operations, voltage supply to the motor increases with the increase of the speed through the electronic converter while the flux is kept constant. At the point of base speed, the voltage of the motor reaches the source voltage. After the base speed, the motor voltage is kept constant and the flux is weakened, dropping hyperbolically with increasing speed. Hence, its torque also drops hyperbolically with increasing speed.

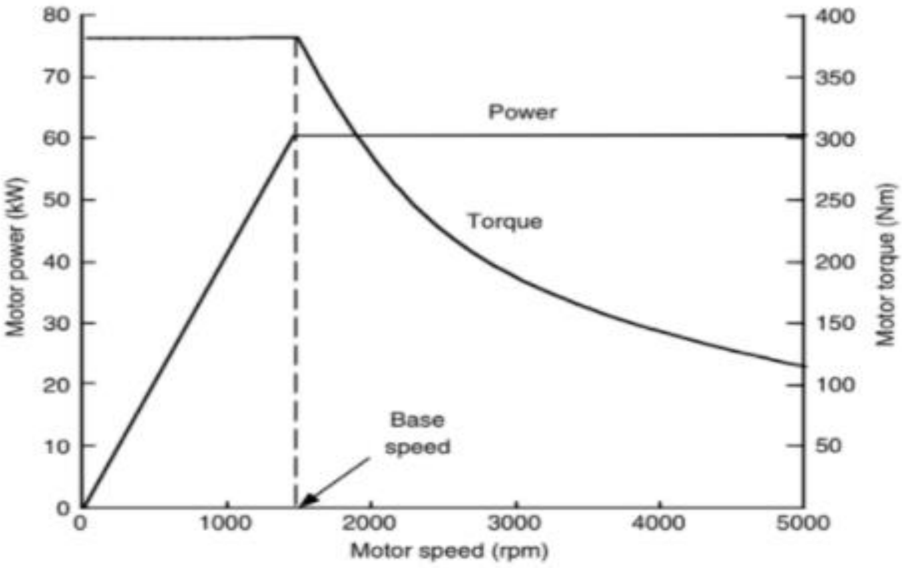


Fig. 2.3. Typical variable-speed electric motor characteristics

2.5M for description

2.5M for Graphs

2.

2.2.3 Vehicle Performance:

Basic vehicle performance includes maximum cruising speed, gradeability, and acceleration. The maximum speed of a vehicle can be easily found by the intersection point of the tractive effort curve with the resistance curve (rolling resistance plus aerodynamic drag), in the tractive effort vs. vehicle speed diagram shown in fig 2.4 to 2.6.

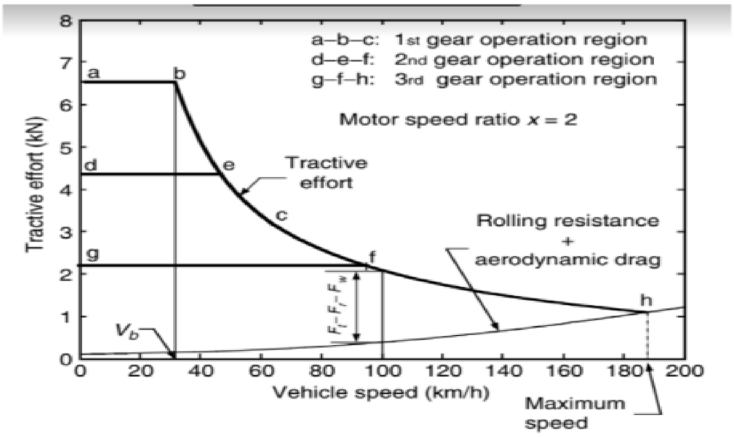


Fig. 2.4: Tractive effort vs. vehicle speed with a traction motor of x =2 and three-gear transmission

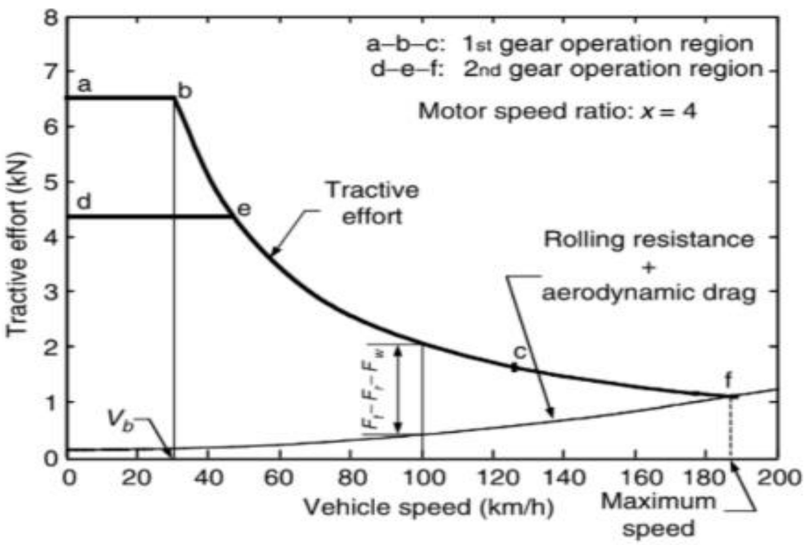


Fig. 2.5: Tractive effort vs. vehicle speed with a traction motor of x=4 and two-gear transmission

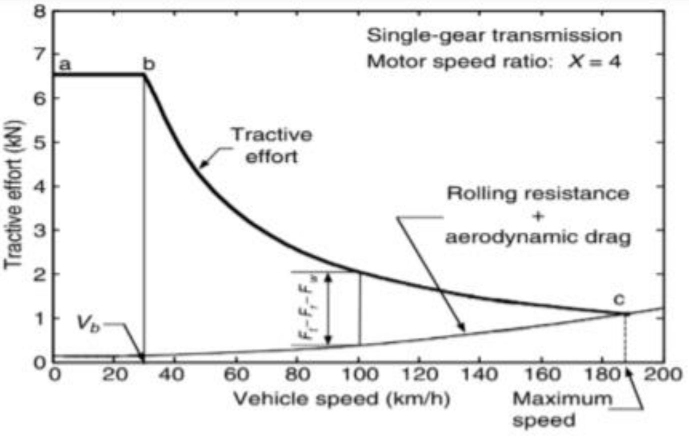


Fig. 2.6: Tractive effort vs. vehicle speed with a traction motor of x6 and single-gear transmission

It should be noted that such an intersection point does not exist in some designs, which usually use a larger traction motor or a large gear ratio. In this case, the maximum vehicle speed is determined by the maximum speed of the traction motor as

$$V_{max} = \frac{\pi N_{m\ max} r_d}{30 i_{g\ min} i_0}$$

where $N_{m\ max}$ is the allowed maximum rpm of the traction motor and

$i_{g\ min}$ is the minimum gear ratio of the transmission (highest gear).

Gradeability is determined by the net tractive effort of the vehicle, $F_{t-net}(F_{t-net} = F_t - F_r - F_w)$, as shown in Figures 2.4–2.6. At mid- and high speeds, the gradeability is smaller than the gradeability at low speeds. The maximum grade that the vehicle can overcome at the given speed can be calculated by

$$i = \frac{F_{t-net}}{M_v g} = \frac{F_t - (F_r + F_w)}{M_v g}$$

where F_t is the tractive effort on the driven wheels

F_r is the tire rolling resistance, and

F_w is the aerodynamic drag.

Acceleration performance of a vehicle is evaluated by the time used to accelerate the vehicle from a low-speed V1 (usually zero) to a higher speed (100 km/h for passenger cars). For passenger cars, acceleration performance is more important than maximum cruising speed and gradeability, since

3Graphs-6M
Description-2M
Formulas-2M

3.

List of architecture-2M

Series hybrid-4M

Parallel hybrid-4M

2.6 Architectures of Hybrid Electric Drive Trains

The architecture of a hybrid vehicle is loosely defined as the connection between the components that define the energy flow routes and control ports. Traditionally, HEVs were classified into two basic types: series and parallel. It is interesting to note that, in 2000, some newly introduced HEVs could not be classified into these kinds.5 Therefore, HEVs are now classified into four kinds: series hybrid, parallel hybrid, series–parallel hybrid, and complex hybrid,

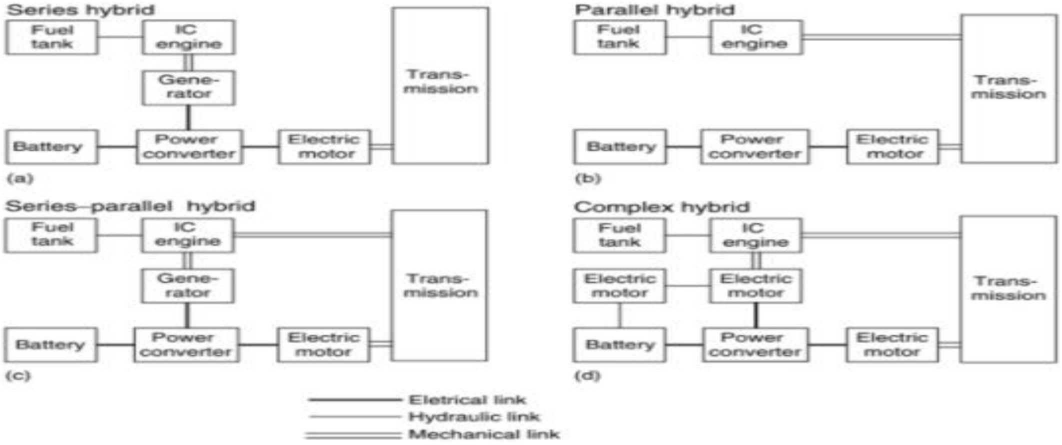


Fig. 2.8: Classification of hybrid electric vehicles

2.6.1 Series Hybrid Electric Drive Trains:

A series hybrid drive train is a drive train where two power sources feed a single powerplant (electric motor) that propels the vehicle. The most commonly found series hybrid drive train is the series hybrid electric drive train shown in Figure 2.9. The unidirectional energy source is a fuel tank and the unidirectional energy converter is an engine coupled to an electric generator. The output of the electric generator is connected to an electric power bus through an electronic converter (rectifier). The bidirectional energy source is an electrochemical battery pack, connected to the bus by means of a power electronics converter (DC/DC converter). The electric power bus is also connected to the controller of the electric traction motor. The traction motor can be controlled either as a motor or a generator, and in forward or reverse motion. This drive train may need a battery charger to charge the batteries by a wall plug-in from the power network.

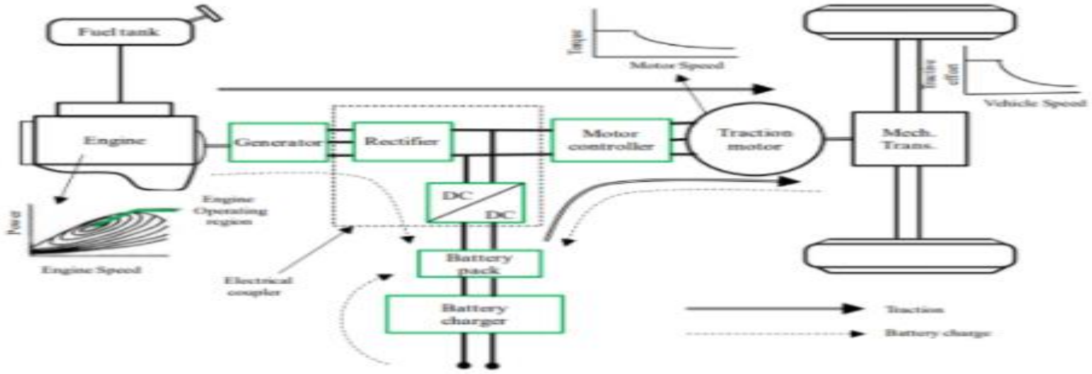


Fig. 2.9: Configuration of a series hybrid electric drive train

Series hybrid electric drive trains potentially have the following operation modes:

. Pure electric mode: The engine is turned off and the vehicle is propelled only by the batteries.

2. Pure engine mode: The vehicle traction power only comes from the engine-generator, while the batteries neither supply nor draw any power from the drive train. The electric machines serve as an electric transmission from the engine to the driven wheels.

3. Hybrid mode: The traction power is drawn from both the engine generator and the batteries.

4. Engine traction and battery charging mode: The engine-generator supplies power to charge the batteries and to propel the vehicle.

5. Regenerative braking mode: The engine-generator is turned off and the traction motor is operated as a generator. The power generated is used to charge the batteries.

6. Battery charging mode: The traction motor receives no power and the engine-generator charges the batteries.

7. Hybrid battery charging mode: Both the engine-generator and the traction motor operate as generators to charge the batteries.

Series hybrid drive trains offer several advantages:

1. The engine is fully mechanical when decoupled from the drive wheels. Therefore, it can be operated at any point on its speed–torque characteristic map, and can potentially be operated solely within its maximum efficiency region.
2. Simple control strategies may be used as a result of the mechanical decoupling provided by the electrical transmission.

However, series hybrid electric drive trains have some disadvantages:

1. The energy from the engine is converted twice (mechanical to electrical in the generator and electrical to mechanical in the traction motor). The inefficiencies of the generator and traction motor add up and the losses may be significant.

2. The generator adds additional weight and cost.

3. The traction motor must be sized to meet maximum requirements since it is the only powerplant propelling the vehicle. [redacted]

2.6.2 Parallel Hybrid Electric Drive Trains:

A parallel hybrid drive train is a drive train in which the engine supplies its power mechanically to the wheels like in a conventional ICE-powered vehicle. It is assisted by an electric motor that is mechanically coupled to the transmission. The powers of the engine and electric motor are coupled together by mechanical coupling, as shown in Figure 2.10. The mechanical combination of the engine and electric motor power leaves room for several different configurations like

1.Torque-Coupling Parallel Hybrid Electric Drive Trains

2. Speed-Coupling Parallel Hybrid Electric Drive Trains

3. Torque-Coupling and Speed-Coupling Parallel Hybrid Electric Drive Trains

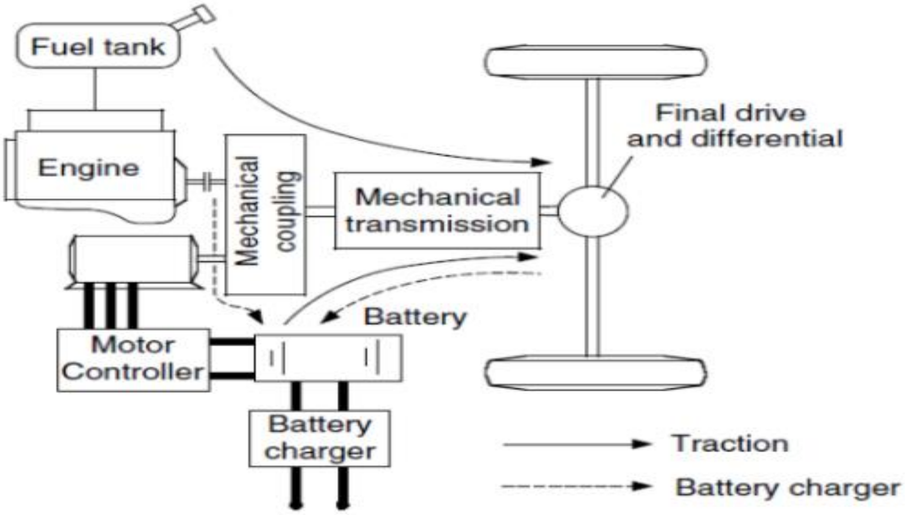


Fig. 2.10: Configuration of a parallel hybrid electric drive train

4. i)

BATTERY CAPACITY

It determines for number of hours for which the battery can be discharged at a constant current to a defined cutoff voltage.

It is represented by the SI unit (Amperes per second) but since this unit is usually very small, the Ampere-hour (Ah) unit is used instead.

We know that a Coulomb is one amp in one second
Therefore 1 Ah = 3600 C.

The capacity of any battery depends on

1. **The Ambient temperature**
2. **The Age of the battery**
3. **The Discharge rate.**

Higher the discharge rate, the lower the capacity, although it affects each battery technology differently.

Additional to the Ampere-hour unit, the storage capacity can also be defined in Watt-hours (Wh=V x Ah), where 1 Wh = 3600 J.

ii)

STATE OF CHARGE (SOC)

The state of charge (SoC) represents the present capacity of the battery. It is the amount of capacity that remains after discharge from a top-of-charge condition

For Example:

It gives the ratio of the amount of energy presently stored in the battery to the nominal rated capacity.

For example,

If a battery is at 80% SOC and with a 500 Ah capacity, the energy stored (available) in the battery is 400 Ah.

iii)

DISCHARGE RATE (C RATE)

It is a measure of the rate at which a battery is discharged relative to its maximum capacity. The notation to specify battery capacity in this way is written as C_x, where x is the time in hours that it takes to discharge the battery.

For Example:

If the capacity of a battery is C = 100 A h.

Then,

For a discharge rate of $\frac{C}{5}$ or C_5

The rate of discharge is $= \frac{100\ \text{Ah}}{5\ \text{h}} = 20\text{A}$

Similarly

For a discharge rate of $\frac{C}{0.5}$, 2C, $C_{0.5}$

The rate of discharge is $= \frac{100\ \text{Ah}}{0.5\ \text{h}} = 200\text{A}$

iv)

DEPTH OF DISCHARGE (DOD)

The depth of discharge (DoD) is the percentage of battery rated capacity to which a battery is discharged.

In many types of batteries, the full energy stored in the battery cannot be withdrawn (in other words, the battery cannot be fully discharged) without causing serious, and often irreparable damage to the battery.

The Depth of Discharge (DOD) of a battery determines the fraction of power that can be withdrawn from the battery. If the DOD of a battery is given by the manufacturer as 25%, then only 25% of the battery capacity can be used by the load.

For example:

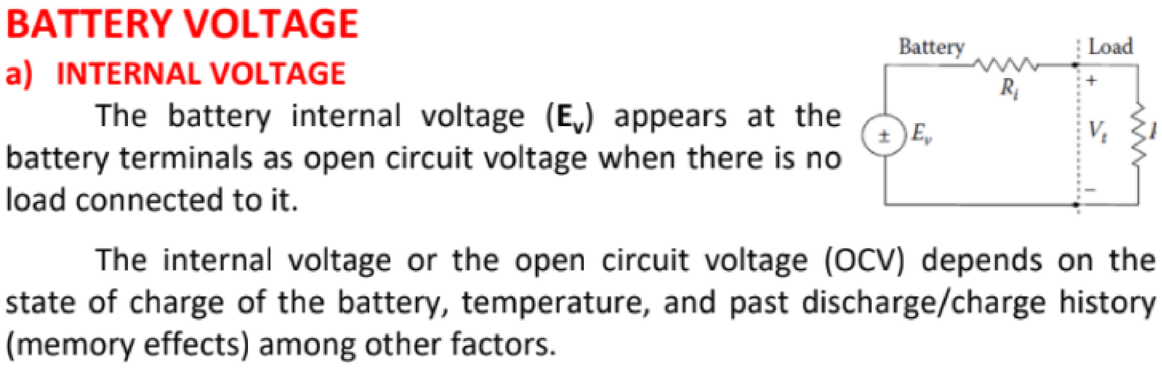
A battery of 500 Ah capacity with a DOD of 20% can only provide

500Ah x 0.2 = 100 Ah.

A battery of 500 Ah capacity with a DOD of 50% can only provide

500Ah x 0.5 = 250 Ah.

v)



BATTERY VOLTAGE

a) INTERNAL VOLTAGE

The battery internal voltage (**E_v**) appears at the battery terminals as open circuit voltage when there is no load connected to it.

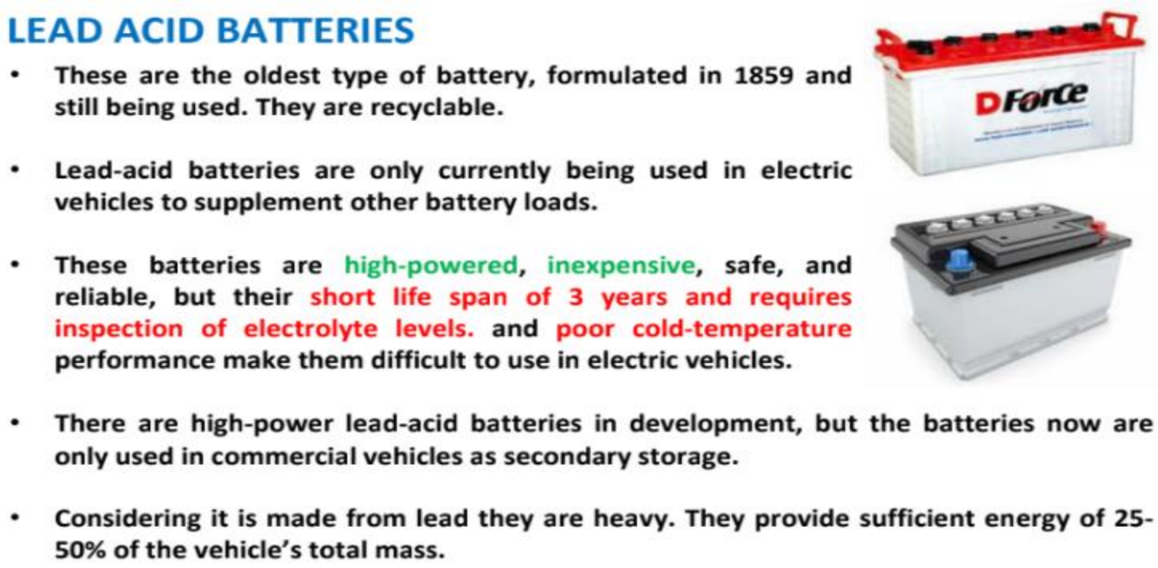
The internal voltage or the open circuit voltage (OCV) depends on the state of charge of the battery, temperature, and past discharge/charge history (memory effects) among other factors.

2M for each parameter

5.

TYPES OF BATTERIES USED IN EVs

- **Lead-Acid Batteries**
- **Lithium-ion batteries**
  - Lithium—Polymer (Li—P) Battery
  - Lithium-Ion (Li-Ion) Battery
- **Nickel-based Batteries**
  - Nickel/Iron System
  - Nickel/Cadmium System
  - Nickel-Metal Hydride (Ni-MH) Batt
- **Ultracapacitors**



LEAD ACID BATTERIES

- These are the oldest type of battery, formulated in 1859 and still being used. They are recyclable.
- Lead-acid batteries are only currently being used in electric vehicles to supplement other battery loads.
- These batteries are high-powered, inexpensive, safe, and reliable, but their short life span of 3 years and requires inspection of electrolyte levels. and poor cold-temperature performance make them difficult to use in electric vehicles.
- There are high-power lead-acid batteries in development, but the batteries now are only used in commercial vehicles as secondary storage.
- Considering it is made from lead they are heavy. They provide sufficient energy of 25-50% of the vehicle’s total mass.

LITHIUM-ION BATTERIES

- Lithium ion (li-ion) battery, the name may sound familiar, these batteries are also used in most portable electronics, including cell phones and computers.
- Lithium ion (li-ion) batteries are now considered to be the standard for modern battery electric vehicles.
- Compared to other mature battery technologies, li-ion offers many benefits. For example,
  - It has excellent specific energy (140 Wh/kg) and energy density, making it ideal for battery electric vehicles.
  - Li-ion batteries are also excellent in retaining energy, with a self-discharge rate (5% per month.

LITHIUM-ION BATTERIES

- However, li-ion batteries also have some drawbacks as well.
  - Very expensive battery technology.
  - Major safety concerns regarding the overcharging and overheating of these batteries.
  - Li-ion can experience a thermal runaway, which can trigger vehicle fires or explosions leading fluctuating charging or damage to the battery.

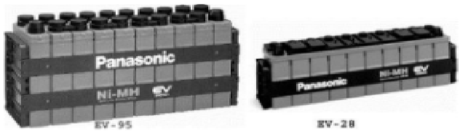
NICKEL-METAL HYDRIDE BATTERIES

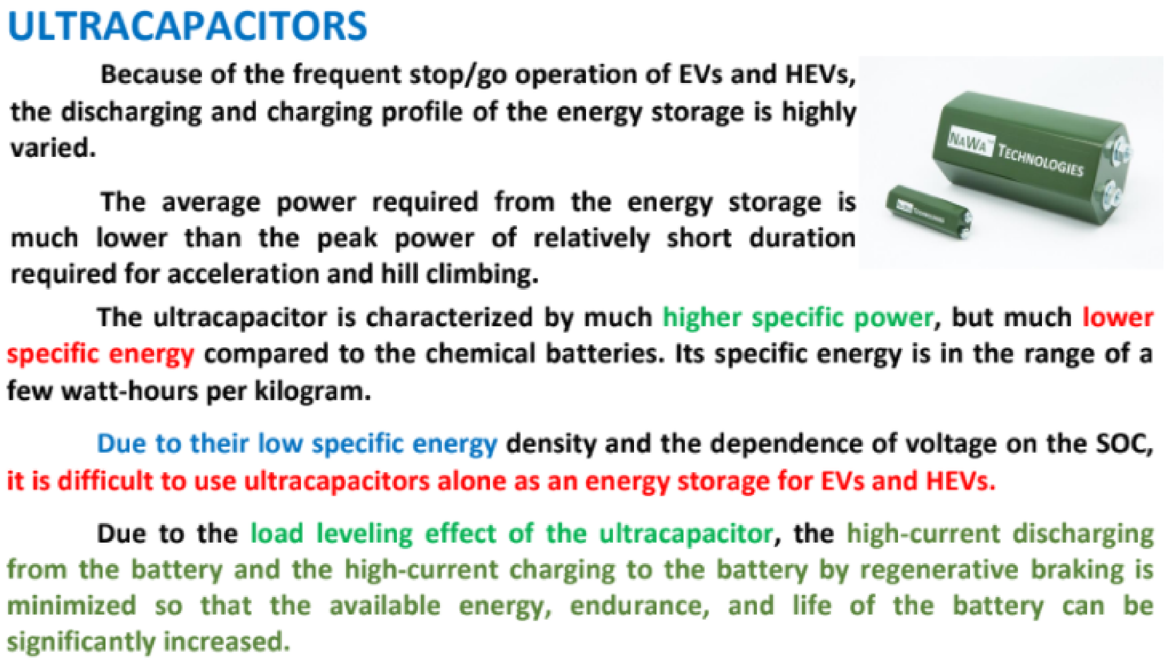
Nickel-metal hydride batteries are more widely used in hybrid-electric vehicles, but are also used successfully in some all-electric vehicles.

Hybrid-electric vehicles do not derive power from an external plug-in source and instead rely on fuel to recharge the battery which excludes them from the definition of an electric car.

Nickel-metal hydride batteries have a longer life-cycle than lithium-ion or lead-acid batteries. They are also safe and tolerant to abuse.

The biggest issues with nickel-metal hydride batteries is their high cost, high self-discharge rate, and the fact that they generate significant heat at high temperatures. These issues make these batteries less effective for rechargeable electric vehicles, which is why they are primarily used in hybrid electric vehicles.





ULTRACAPACITORS

Because of the frequent stop/go operation of EVs and HEVs, the discharging and charging profile of the energy storage is highly varied.

The average power required from the energy storage is much lower than the peak power of relatively short duration required for acceleration and hill climbing.

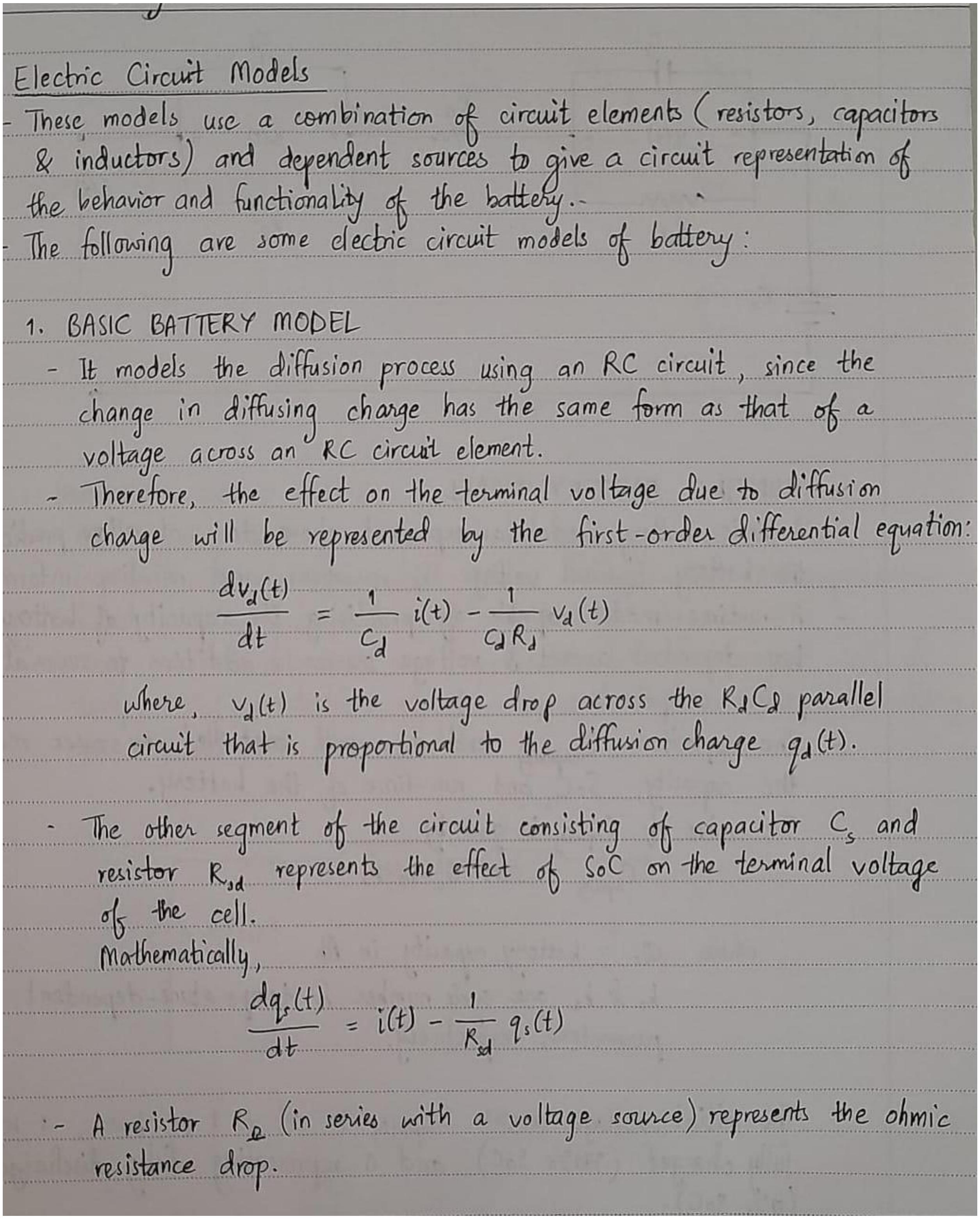
The ultracapacitor is characterized by much higher specific power, but much lower specific energy compared to the chemical batteries. Its specific energy is in the range of a few watt-hours per kilogram.

Due to their low specific energy density and the dependence of voltage on the SOC, it is difficult to use ultracapacitors alone as an energy storage for EVs and HEVs.

Due to the load leveling effect of the ultracapacitor, the high-current discharging from the battery and the high-current charging to the battery by regenerative braking is minimized so that the available energy, endurance, and life of the battery can be significantly increased.

List of batteries and types of batteries-10M

6.



Electric Circuit Models

- These models use a combination of circuit elements (resistors, capacitors & inductors) and dependent sources to give a circuit representation of the behavior and functionality of the battery.
- The following are some electric circuit models of battery:

1. BASIC BATTERY MODEL
   - It models the diffusion process using an RC circuit, since the change in diffusing charge has the same form as that of a voltage across an RC circuit element.
   - Therefore, the effect on the terminal voltage due to diffusion charge will be represented by the first-order differential equation:

$$\frac{dv_d(t)}{dt} = \frac{1}{C_d} i(t) - \frac{1}{C_d R_d} v_d(t)$$

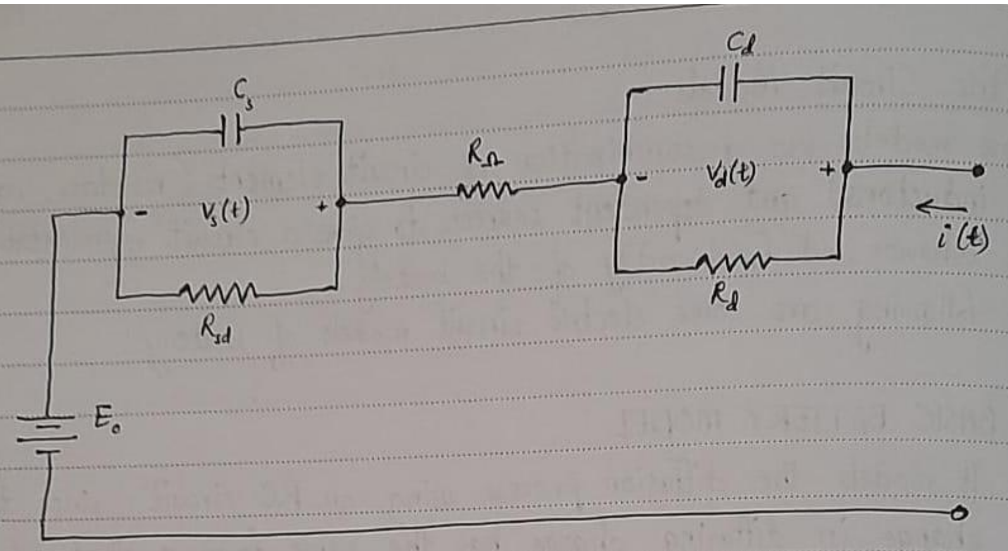
where, $v_d(t)$ is the voltage drop across the $R_d C_d$ parallel circuit that is proportional to the diffusion charge $q_d(t)$.

- The other segment of the circuit consisting of capacitor C_s and resistor R_{sd} represents the effect of SoC on the terminal voltage of the cell.

Mathematically,

$$\frac{dq_s(t)}{dt} = i(t) - \frac{1}{R_{sd}} q_s(t)$$

- A resistor R_Ω (in series with a voltage source) represents the ohmic resistance drop.



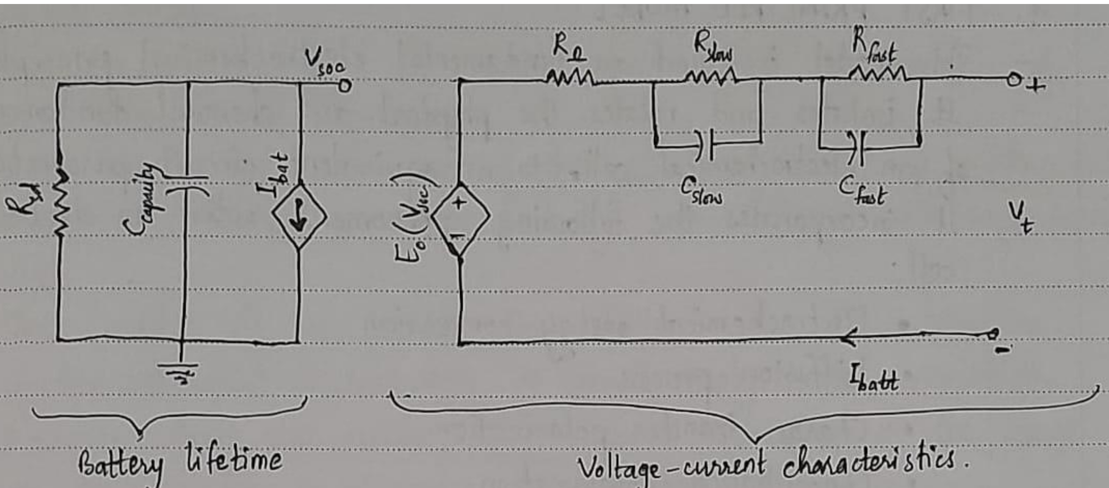
2. RUNTIME BATTERY MODEL

- A basic battery model as explained above does not allow prediction of the battery terminal voltage V_t variations and run-time information.
- A runtime model capable of practising the capacity of battery has dependent current & voltage sources in addition to several passive components.
- The capacitor $C_{capacity}$ and a current-controlled source model the capacity, SoC, and run-time of the battery.
- The value of $C_{capacity}$ is given by

$$C_{capacity} = 3600 \cdot Q_c \cdot k_1 \cdot k_2$$

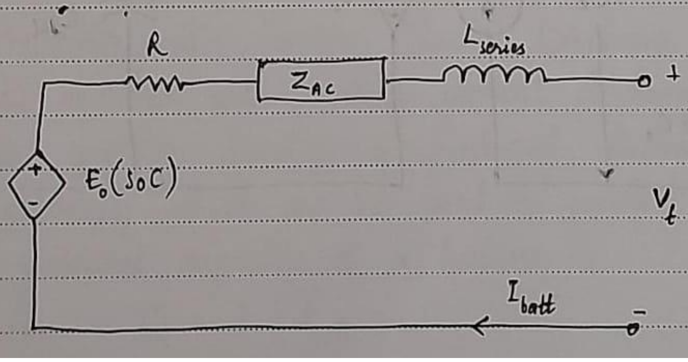
where Q_c = battery capacity in Ah
k_1 & k_2 are cycle number & temperature-dependent correction parameters, respectively.

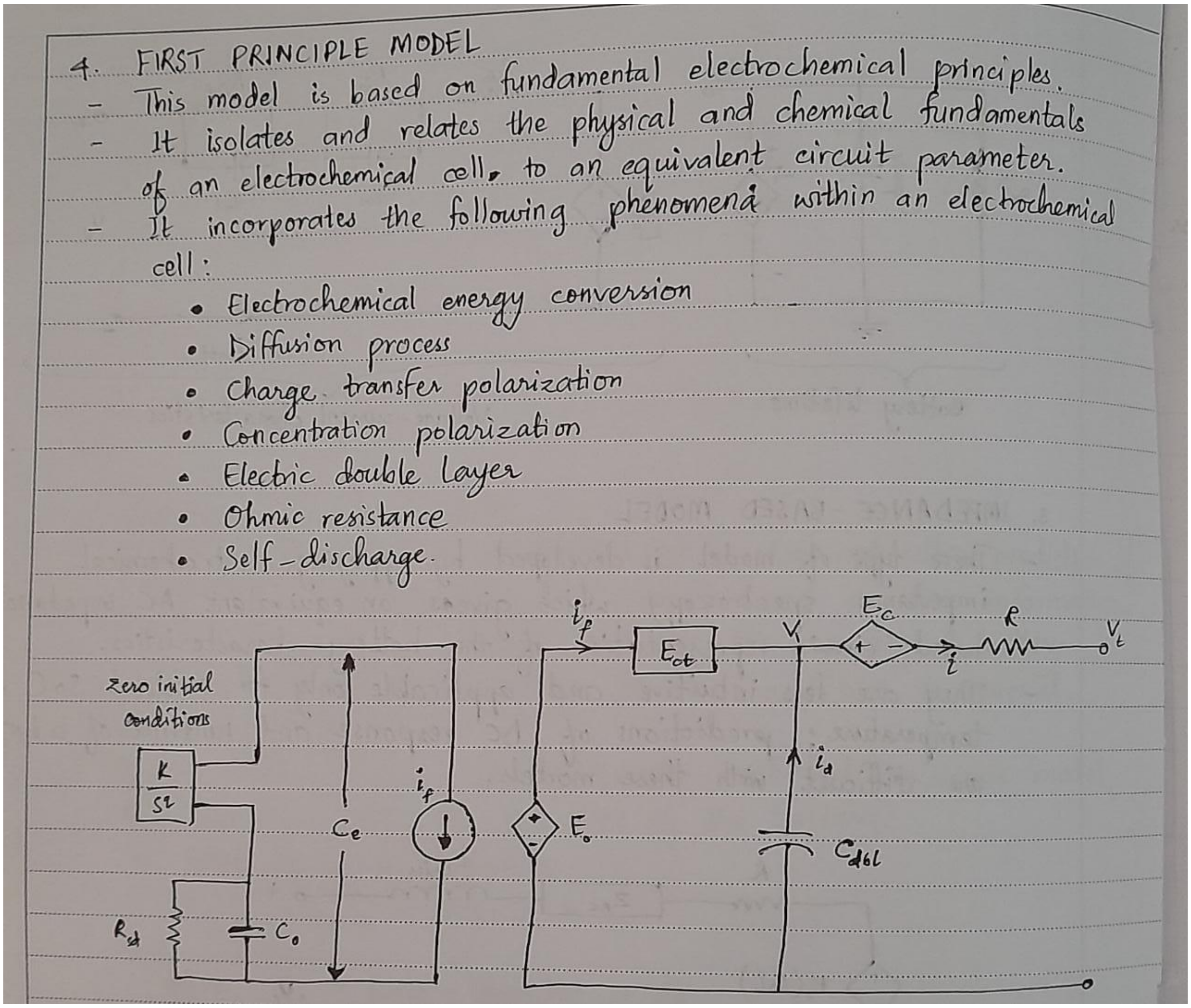
- The initial voltage across $C_{capacity}$ is set to 1 or lower, 1 representing fully charged (100% SoC) and 0 representing fully discharged (0% SoC).



3. IMPEDANCE-BASED MODEL

- These type of model is developed by applying electrochemical impedance spectroscopy which gives an equivalent AC impedance-based circuit representation of the battery characteristics.
- They are less intuitive and applicable only for constant SoC & temperature; predictions of DC response and runtime of a battery are difficult with these models.





4. FIRST PRINCIPLE MODEL

- This model is based on fundamental electrochemical principles.
- It isolates and relates the physical and chemical fundamentals of an electrochemical cell, to an equivalent circuit parameter.
- It incorporates the following phenomena within an electrochemical cell:
  - Electrochemical energy conversion
  - Diffusion process
  - Charge transfer polarization
  - Concentration polarization
  - Electric double layer
  - Ohmic resistance
  - Self-discharge.

Electric circuit model-2M

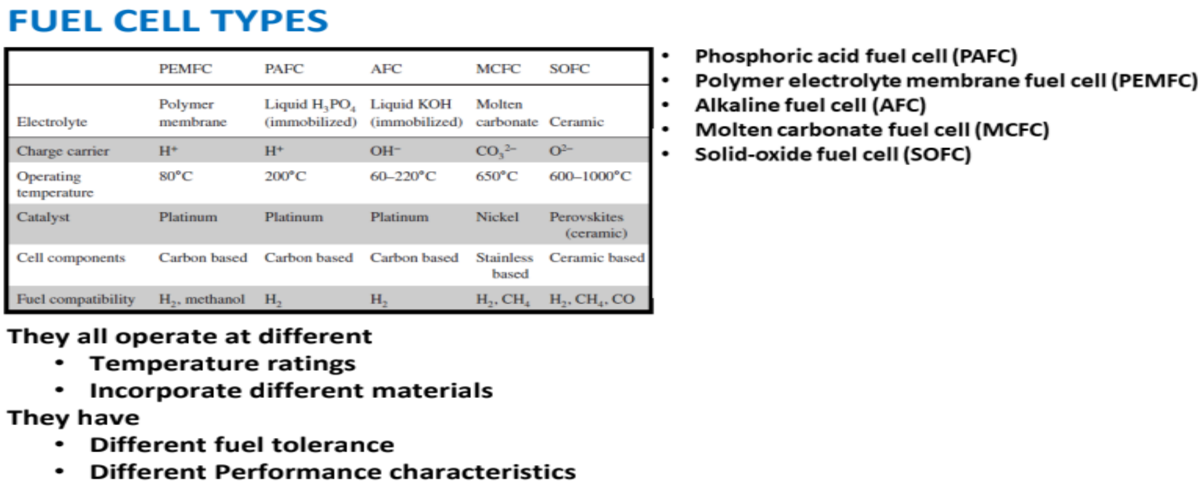
4 different models-4*2=8M

7.

List of fuel cells- 4M

PEMFC diagram and description -4M

Equations-2M



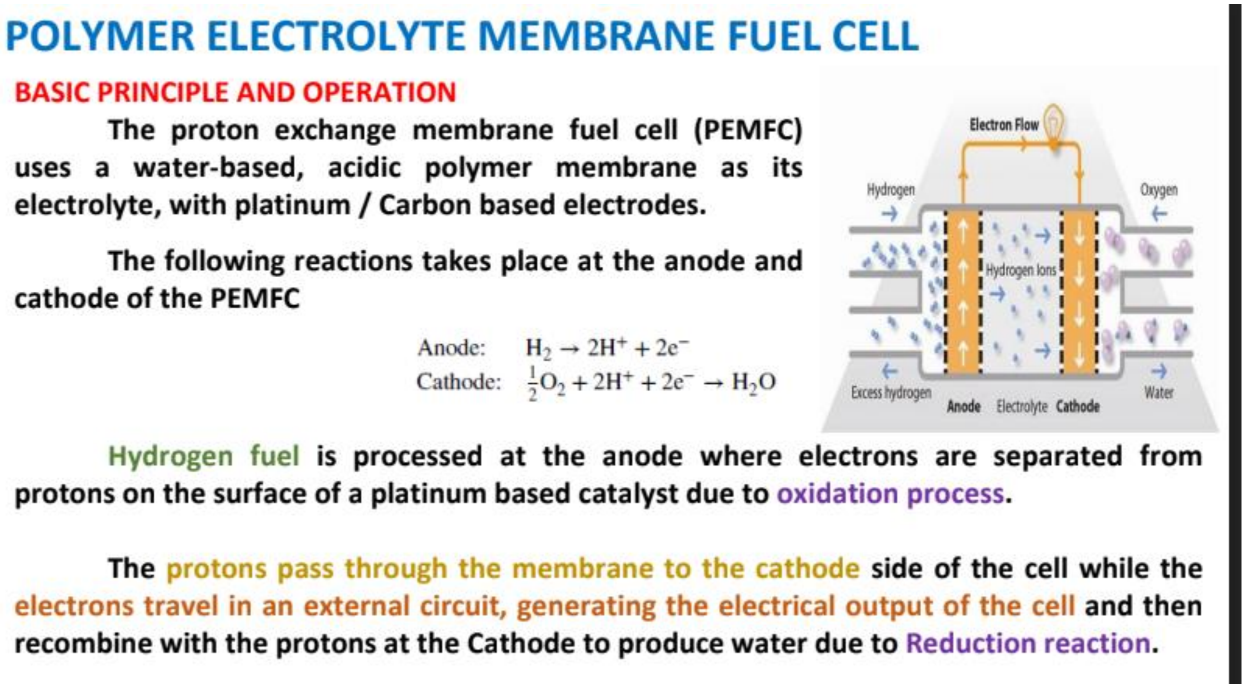
FUEL CELL TYPES

	PEMFC	PAFC	AFC	MCFC	SOFC
Electrolyte	Polymer membrane	Liquid H_3PO_4 (immobilized)	Liquid KOH (immobilized)	Molten carbonate	Ceramic
Charge carrier	H^+	H^+	OH^-	CO_3^{2-}	O^{2-}
Operating temperature	80°C	200°C	60–220°C	650°C	600–1000°C
Catalyst	Platinum	Platinum	Platinum	Nickel	Perovskites (ceramic)
Cell components	Carbon based	Carbon based	Carbon based	Stainless based	Ceramic based
Fuel compatibility	H_2, methanol	H_2	H_2	H_2, CH_4	H_2, CH_4, CO

- **Phosphoric acid fuel cell (PAFC)**
- **Polymer electrolyte membrane fuel cell (PEMFC)**
- **Alkaline fuel cell (AFC)**
- **Molten carbonate fuel cell (MCFC)**
- **Solid-oxide fuel cell (SOFC)**

They all operate at different
  - **Temperature ratings**
  - **Incorporate different materials**

They have
  - **Different fuel tolerance**
  - **Different Performance characteristics**



POLYMER ELECTROLYTE MEMBRANE FUEL CELL

BASIC PRINCIPLE AND OPERATION

The proton exchange membrane fuel cell (PEMFC) uses a water-based, acidic polymer membrane as its electrolyte, with platinum / Carbon based electrodes.

The following reactions takes place at the anode and cathode of the PEMFC

$$\text{Anode:} \quad H_2 \rightarrow 2H^+ + 2e^-$$
$$\text{Cathode:} \quad \tfrac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$$

Hydrogen fuel is processed at the anode where electrons are separated from protons on the surface of a platinum based catalyst due to oxidation process.

The protons pass through the membrane to the cathode side of the cell while the electrons travel in an external circuit, generating the electrical output of the cell and then recombine with the protons at the Cathode to produce water due to Reduction reaction.

POLYMER ELECTROLYTE MEMBRANE FUEL CELL

Hydrogen is the fuel of for low-power (<1kW) applications, for high-power (>1kW) applications liquid fuels such as methanol and formic acid are also considered. The operating temperature of the PEMFC is limited to 90∘C or lower

PEMFC cells are currently the leading technology for light-duty vehicles and materials handling vehicles, and to a lesser extent for stationary and other applications. The PEMFC fuel cell is also sometimes called a polymer electrolyte membrane fuel cell (also PEMFC).

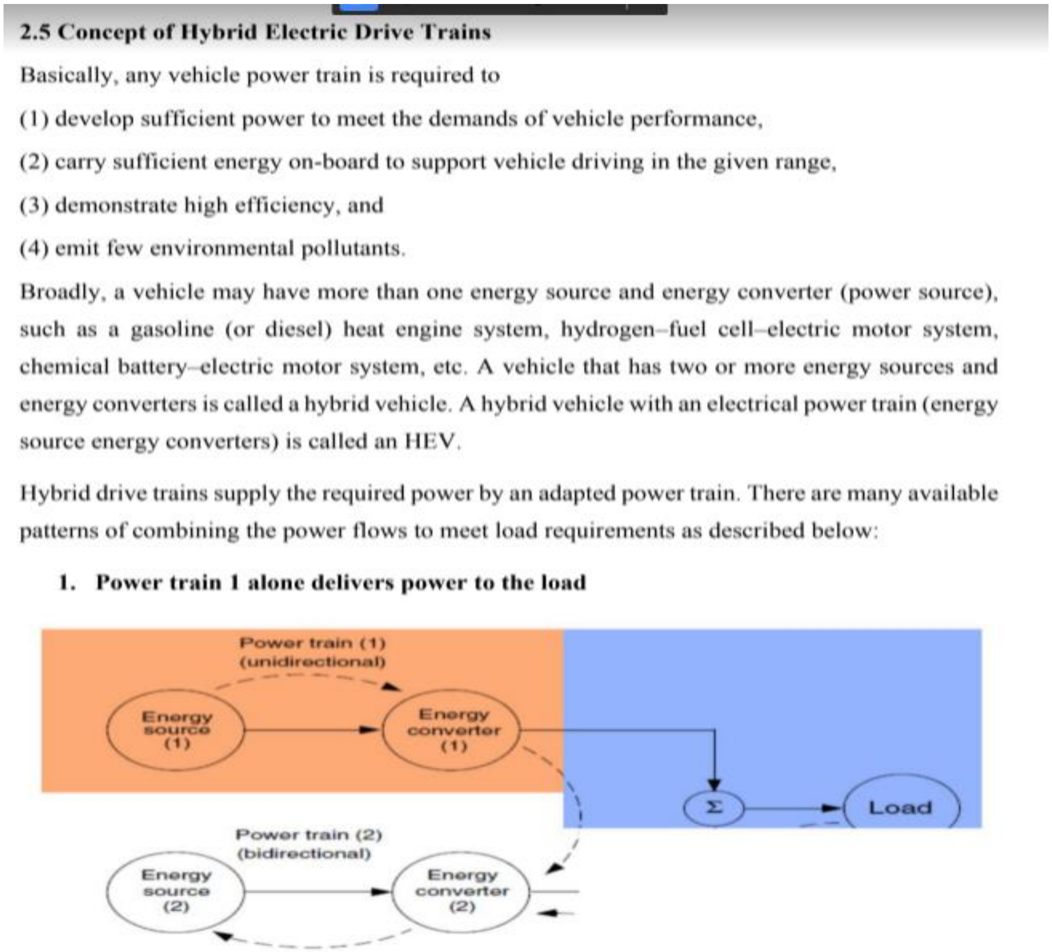
ADVANTAGES

- **Highest power density of all the fuel cell classes**
- **Good start–stop capabilities**
- **Low-temperature operation makes it suitable for portable applications**

DISADVANTAGES

- **Uses expensive platinum catalyst**
- **Polymer membrane and ancillary components are expensive**
- **Active water management is often required**

8.



2.5 Concept of Hybrid Electric Drive Trains

Basically, any vehicle power train is required to

(1) develop sufficient power to meet the demands of vehicle performance,

(2) carry sufficient energy on-board to support vehicle driving in the given range,

(3) demonstrate high efficiency, and

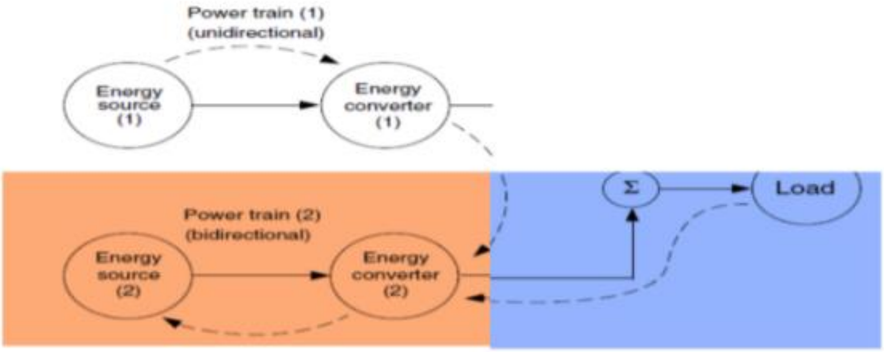
(4) emit few environmental pollutants.

Broadly, a vehicle may have more than one energy source and energy converter (power source), such as a gasoline (or diesel) heat engine system, hydrogen–fuel cell–electric motor system, chemical battery–electric motor system, etc. A vehicle that has two or more energy sources and energy converters is called a hybrid vehicle. A hybrid vehicle with an electrical power train (energy source energy converters) is called an HEV.

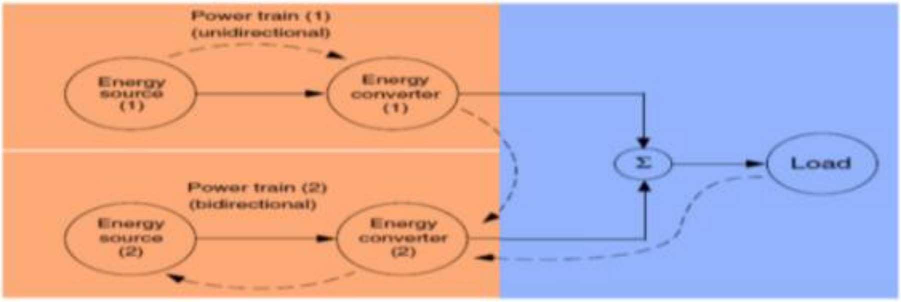
Hybrid drive trains supply the required power by an adapted power train. There are many available patterns of combining the power flows to meet load requirements as described below:

1. **Power train 1 alone delivers power to the load**

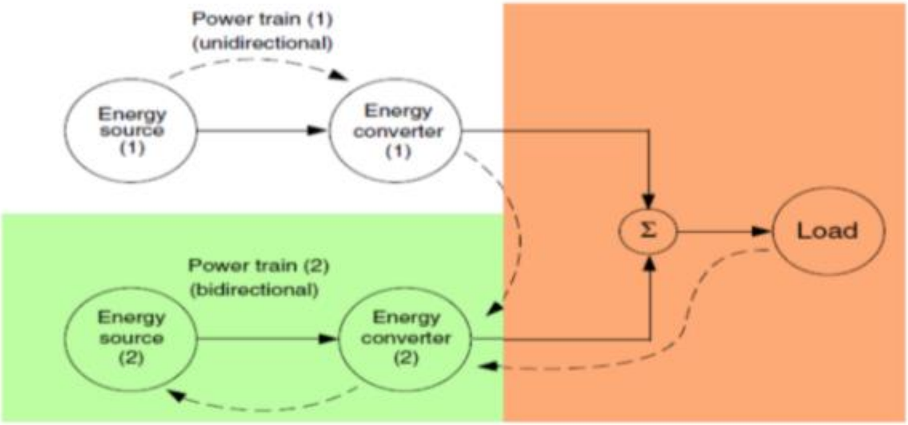
2. **Power train 2 alone delivers power to the load**



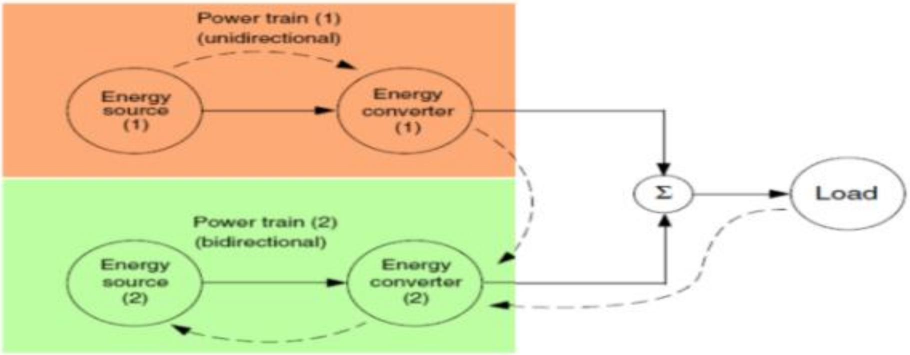
3. **Both power train 1 and 2 deliver power to load at the same time**



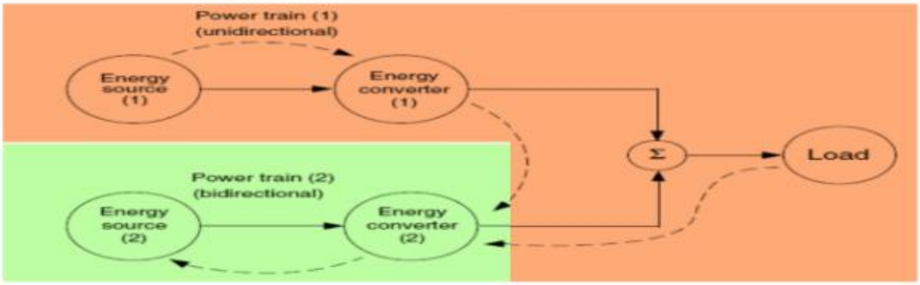
4. **Power train 2 obtains power from load (regenerative braking)**



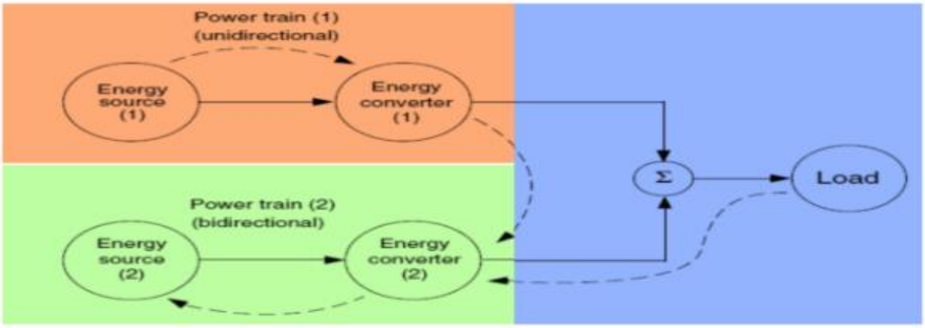
5. Power train 2 obtains power from power train 1



6. Power train 2 obtains power from power train 1 and load at the same time



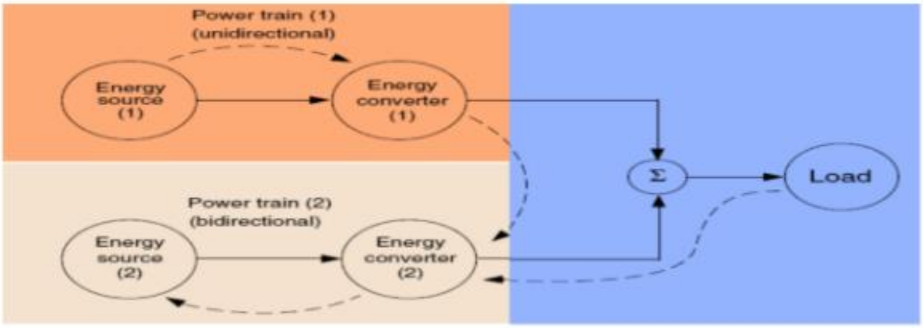
7. Power train 1 delivers power to load and to power train 2 at the same time



9 configurations-9M

For neat diagrams-1M

8. **Power train 1 delivers power to power train 2, and power train 2 delivers power to load**



9. **Power train 1 delivers power to load, and load delivers power to power train 2**