CMR INSTITUTE OF TECHNOLOGY

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Internal Assessment Test - II

Sub:	**Electric Vehicles**							Code:	21EE752
Date:	19/11/2024	Duration:	90 mins	Max Marks:	50	Sem:	6th	Branch:	OE-ECE, AIML, CIVIL, CSE

Answer Any FIVE FULL Questions

		Marks	OBE CO	OBE RBT
1	List out different types of fuel cells and explain in detail about Proton exchange membrane fuel cell	10	CO3	L2

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**

Proton Exchange Membrane Fuel cell (PEMFC)
(Low temperature FC).

=> used Solid electrolytes — Nafion

=> low temp operates (80°C)

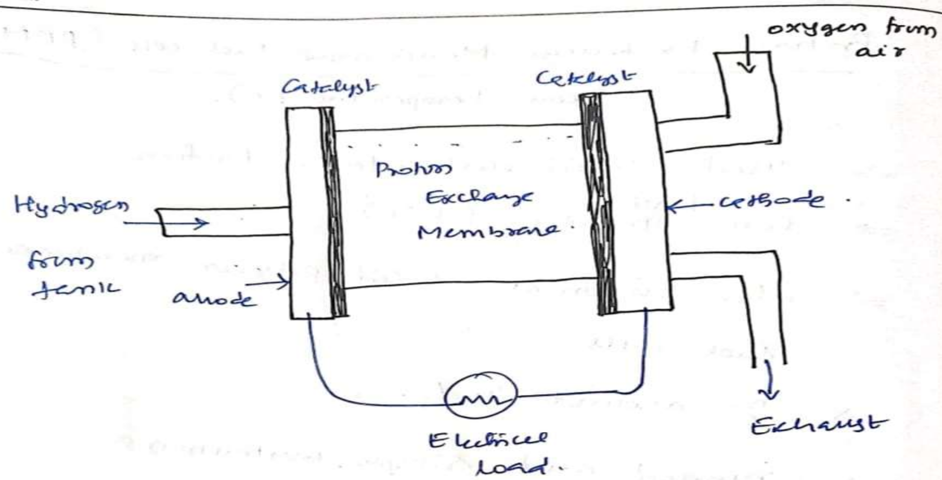
=> also known as Solid polymer membrane fuel cells

=> η around 40%.

=> rugged and simple constructions
↓
highly suitable for vehicle applications.

=> PEM fuel cell and AFC — currently used for vehicle applications.

=> Adv. of PEM cell is that they can tolerate impurity in the fuel as compared to pure hydrogen needed in AFC's.



At anode:

$$H_2 \longrightarrow 2H^+ + 2e^-$$

At cathode:

$$2H^+ + \frac{1}{2}O_2 + 2e^- \longrightarrow H_2O.$$

Overall Reaction:

$$H_2(gas) + \frac{1}{2}O_2(gas) \rightarrow H_2O + \text{heat} + \text{electrical work.}$$

⇒ Due to the relatively low temperatures and the use of precious metal based electrodes, these cells must operate on pure hydrogen.

⇒ PEMFC are currently the leading technology and material for light duty vehicles and to a lesser handling vehicles extent for stationary and other applications.

⇒ The proton exchange membrane fuel cell (PEMFC) uses a water based acidic polymer membrane as its electrolyte, with platinum based electrodeles.

⇒ Hydrogen fuel is processed at the anode, where the electrons are separated from protons on the surface of a platinum based catalyst.

⇒ 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.

=> On the cathode side, another precious metal electrode combines the protons and electrons with oxygen to produce water, which is expelled as the only waste product.

=> Oxygen can be provided in pure form (or) extracted at the electrode directly from the air.

=> A variant of the PEMFC which operates at elevated temperatures is known as the high temp PEMFC [HT PEMFC].

=> By changing the electrolyte from being water based to a mineral acid based system, HT PEMFCs can operate up to 200°C.

=> This overcomes some of the current limitations with regard to fuel purity with HT PEMFC's able to process reformate containing small quantities of carbon monoxide. (CO).

2	Discuss about modelling of battery (empirical model and Electric circuit model).	10	CO3	L2

Battery Modelling:

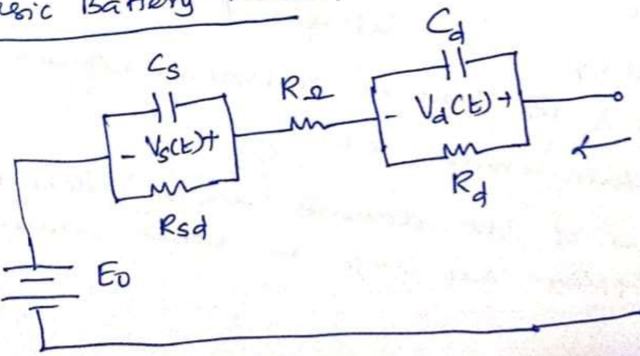
↳ modelled at various levels depending on the use of the model.

↳ useful for battery design, performance evaluation and system simulation at the application level.

↳ aids research on device design, construction and materials usage.

↳ aids to improved design and better utilization.

Basic Battery Model:



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R_{sd} - self discharging resistor.

$V_d(t)$ — voltage drop across R_dC_d parallel ckt that is proportional to the $V_d(t)$.

C_s - stored charge in the cell.

C_s is proportional to the stored charge $q_s(t)$.

=> As the state of charge of the cell ↑ses (or) ↓ses during charging (or) discharging, the voltage across the capacitor also ↑ses (or) ↓ses. respectively.

=> additionally, an electrochemical cell losses charge while it is at rest.

=> A resistor can be added in parallel to the C_s to account for this loss of charge.

=> R_{sd} - represents the self discharge of the cell.

= C_d - diffusion capacitor

=> R_d - diffusion resistor.

=> $C_s R_{sd}$ is series with $C_d R_d$.

=> E_0 - opencircuit voltage

=> R_Ω - is the ohmic resistance. is series with storage and diffusion parameters.

=> this is the complete equivalent circuit model of electrochemical cell.

=> values of ckt elements can be determined by applying step change in battery current.

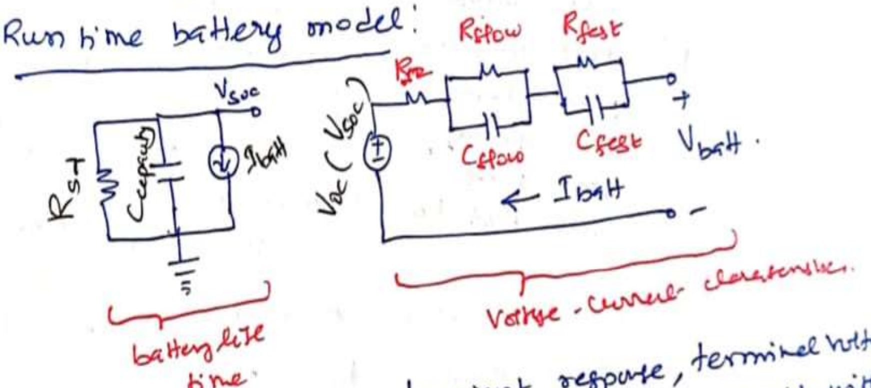
∴ The effect of on the terminal voltage due due to diffusion discharge will be represented by the following first order differential equation.

$$\frac{d V_d(t)}{dt} = \frac{1}{C_d} i(t) - \frac{1}{C_d R_d} V_d(t)$$

∴ The mathematical representation of this segment of the circuit model in relation to the terminal current is

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

(i) Run time battery model:



=> Prediction of SoC, transient response, terminal voltage and temperature effects is possible with run time models.

$C_{capacity} = 3{,}600\, Q_c K_1 K_2$

→ battery capacity

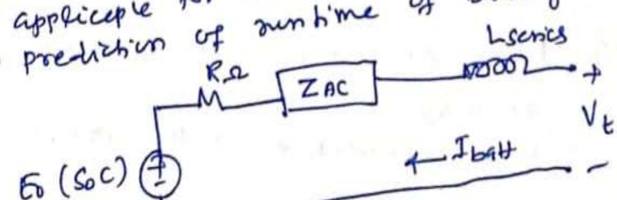
→ cycle number and temperature dependent correction parameters.

(ii) Impedance - Base Model:

↳ model based on impedance spectroscopy.

↳ applicable for fixed SoC and temp.

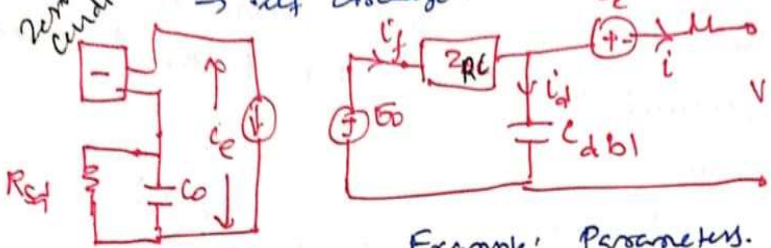
↳ prediction of run time of battery is difficult.



(iii) First Principle Model: Isolates and relates the physical and chemical fundamentals of electro chemical cell to an equivalent circuit parameters.

The first principle model incorporates
- → electrochemical energy conversion
- → Diffusion process
- → Charge transfer polarization
- → concentration polarization
- → Electrical double layer.
- → Ohmic resistance
- → self discharge.

Zero initial conditions



16000 Amm
5000 Ramsh.
8000 Fargosine
1200 Pirese
2000 Festival
3500 Petrol
500 Fest ...

<u>Example</u>: Parameters.

Bulk electrolyte concentration $\} C_0 = 2.616$

diffusion process parameter $\} C_d(t) = C_0 - K\, i_f(t)\, t^q$

$K = \frac{1}{227.5}$; $q = 0.68$

Open circuit voltage $\} E(t) = 1.95 + 0.052 \ln C_d(t)$

E_{ct} - charge transfer polarisation $= 0.118 + 0.28 \ln(i_f)$

Ohmic resistance $R_\Omega = 0.05\,\Omega$

Double layer capacitor $C_{dbl} = 50\,F$

concentration polarization: $E_c(t) = 0.04 \ln \frac{C_d(t)}{C_0}$.

(iv) <u>Empirical models</u>: ⇒ Simplest model

⇒ describe the performance,

→ does not specify the initial capacity, voltage variation and aging factors.

→ does not give i-v information.

(1) Range prediction with constant current discharge

(2) Range prediction with power density approach.

3	Explain in detail about Force velocity characteristics and maximum gradeability.	10	CO1	L2

⇒ Vehicle performance includes

(i) Cruising speed
↓
usually somewhat below maximum, that is comfortable and economical.

(ii) Gradeability
↓
ability to climbing in slopes

(iii) Acceleration.

⇒ The maximum of speed of vehicle can be easily found by
↓
intersection point of the tractive effort curve with the resistance curve (rolling resistance and aerodynamic drag)

⇒ It should be noted such that a intersection point doesnot exist in some designs, which usually use a larger traction motor (or) larger gear ratio.

⇒ In this case, the maximum vehicle speed is determined by

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

where,

$N_{m\,max}$ = allowed max. rpm of the traction motor.

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

The gradeability is calculated as,

~~$i = F_{t\text{-}net}$~~

$$F_{t-net} = F_t - F_r - F_w$$

F_t → tractive effort on the driven wheels

F_r → tyre rolling resistance

F_w → aerodynamic drag.

⇒ The gradeability at mid and high speed is smaller than at low speeds.

⇒ The maximum grade that the vehicle can overcome at the given speed can be calculated by

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

⇒ However, at low speeds, the gradeability is much larger.

where M_g - weight of the vehicle.

Gradeability.

The max. grade / slope that a vehicle will be able to overcome the max. force available from the propulsion unit is known as gradeability.

Assumption for calculating maximum gradability:

⇒ Vehicle is moving very slowly ~ almost zero.

⇒ F_{AD} and F_{rr} is equal to zero

⇒ Acceleration is zero.

⇒ Traction force is max. at nearly zero speed.

Force Required for linear acceleration (F_{LA}).

$F_{LA} = m a = m \frac{dv}{dt}$. ↳ linear accel.

Acceleration force: (Angular Acceleration) (F_{AA}) Torque is also needed to spin the rotating parts within the drive train.

From Newton's second law motion,

$$T = J \frac{d\omega}{dt} = \frac{J}{r} \frac{dv}{dt}$$

↳ radius of the system
↳ moment of inertia

$$F_{AA} = \frac{T}{r} = \frac{J}{r^2} \frac{dv}{dt}.$$

Total Traction effort = Sum of all the forces

$$F_T = \underbrace{F_{rr} + F_g + F_{AD}}_{\text{opposing forces}} + \underbrace{F_{LA} + F_{AA}}_{\text{Aiding forces}}.$$

4	Write a note on i) Constant FTR level road ii) Velocity Profile iii) Distance transversed iv) Tractive power and energy required	10	CO1	L2

i) Constant FTR Level Road

Constant FTR (Force to Traction Ratio) on a level road refers to a scenario where the traction force required to maintain a vehicle's motion is constant. This happens when:

- The road surface is flat and uniform, minimizing resistance due to gradients.
- The driving conditions (speed, wind, and road friction) remain stable.
  In this case, the power needed from the engine to overcome rolling resistance, aerodynamic drag, and mechanical losses remains constant.

ii) Velocity Profile

The velocity profile of a vehicle is a graph or mathematical function that represents how the speed of the vehicle changes with respect to time or distance.

- **Importance:**
  - Helps analyze vehicle performance, fuel efficiency, and adherence to traffic rules.
  - Crucial for optimizing energy consumption in electric or hybrid vehicles.
- **Example:**
  - Constant velocity: Straight, flat line.
  - Accelerating: Upward slope.
  - Decelerating: Downward slope.

iii) Distance Traversed

Distance traversed refers to the total length of the path covered by a vehicle over a specific period of time. It can be calculated using:

$\text{Distance} = \int v(t)\,dt$

where $v(t)$ is the velocity as a function of time.

- **Factors Influencing Distance:**
  - Velocity profile (speed and its variation over time).
  - Road conditions (flat, inclined, rough, etc.).
  - Duration of travel.
- In practical applications, devices like odometers measure this directly.

iv) Tractive Power and Energy Required

Tractive Power:

The power needed to overcome the resistances acting on the vehicle, enabling it to move forward. It is given by:

$P_t = F_t \cdot v$

where:

- F_t = tractive force (sum of rolling resistance, aerodynamic drag, and gradient resistance)
- v = vehicle speed

Energy Required:

The total work done to move the vehicle over a certain distance. It can be expressed as:

$E = \int F_t \cdot dx$

or

$E = P_t \cdot t$ (if P_t is constant).

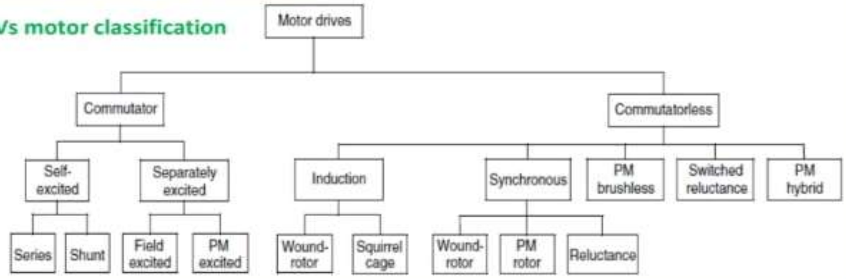
	• **Factors Influencing Tractive Power and Energy:** • Vehicle mass and aerodynamics. • Road gradient and surface type. • Speed of travel. • Environmental conditions (e.g., wind resistance). Efficient vehicle design minimizes tractive power and energy consumption to optimize performance and fuel efficiency.			
5	With the help of circuit diagram and operating characteristics explain the two quadrant zero voltage transition converter for EV DC motor drives.	10	CO4	L2

MOTORS FOR EVs and HEVs

Motors used in EVs and HEVs usually require

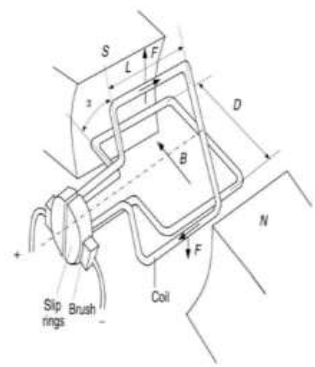
- **Frequent starts and stops**
- **High rates of acceleration/ deceleration**
- **High torque and low-speed hill climbing**
- **Low torque and high-speed cruising**
- **Very wide speed range of operation.**

EVs and HEVs motor classification



DC Motor drives:

- DC motor drives have been widely used in applications requiring adjustable speed, good speed regulation, and frequent starting, braking and reversing.



Principle of Operation:

- When a wire carrying electric current is placed in a magnetic field, a magnetic force acting on the wire is produced. The force is perpendicular to the wire and the magnetic field.
- The magnetic force is proportional to the wire length, magnitude of the electric current, and the density of the magnetic field; that is,

F=BIL

- When the wire is shaped into a coil, the magnetic forces acting on both sides produce a torque, which is expressed as

T=BIL cos α

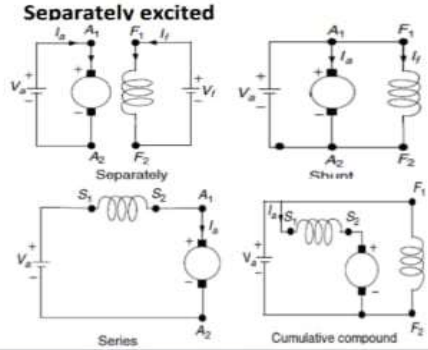
where α is the angle between the coil plane and magnetic field.

DC MOTOR DRIVES

- **Types of DC Motor**

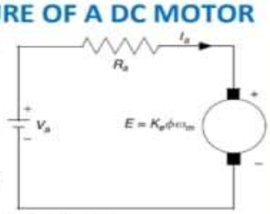
Typically, there are four types of wound-field DC motors, depending on the mutual interconnection between the field and armature windings. They are

- **Separately excited**
- **Shunt excited**
- **Series excited**
- **Compound excited**



STEADY-STATE EQUIVALENT CIRCUIT OF THE ARMATURE OF A DC MOTOR

- **The steady-state equivalent circuit of the armature of a DC motor is shown in figure.**
- **The resistor R_a is the resistance of the armature circuit.**
  - **For separately excited and shunt DC motors, it is equal to the resistance of the armature windings**
  - **For the series and compound motors, it is the sum of armature and series field winding resistances.**



- **Basic equations of a DC motor are**

$$V_a = E + R_a I_a$$

$$I_a = \frac{V_a - E}{R_a}$$

$$E = K_e\phi\omega_m$$

$$T = K_e\phi I_a$$

$$T = K_e\phi\left[\frac{V_a - E}{R_a}\right]$$

$$T = \frac{K_e\phi}{R_a}V - \frac{(K_e\phi)^2}{R_a}\omega_m$$

where

- **I_a is the armature current in Amps**
- **V_a is the armature voltage in Volts**
- **ϕ is the flux per pole in Webers**
- **R_a is the resistance of the armature circuit in ohms**
- **ω_m is the speed of the armature in rad/sec**
- **T is the torque developed by the motor in Nm**
- **K is constant**

6	With the help of block diagram and XY and αβ frame plots, explain field-oriented control of Induction motor drive.	10	CO4	L2

INDUCTION MOTOR DRIVES

- **Commutator less motor drives offer a number of advantages over conventional DC commutator motor drives for the electric propulsion of EVs and HEVs.**
- **At present, induction motor drives are the mature technology among commutator less motor drives. Compared with DC motor drives, the AC induction motor drive has additional advantages such as**
  - **LIGHTWEIGHT NATURE**
  - **SMALL VOLUME**
  - **LOW COST**
  - **HIGH EFFICIENCY.**

  which are particularly important for EV and HEV applications.
- **There are two types of induction motors, namely, wound-rotor and squirrel cage motors.**
- **Because of the high cost, need for maintenance, and lack of sturdiness, wound-rotor induction motors are less attractive**
- **squirrel-cage motors are preferred for electric propulsion in EVs and HEVs.**

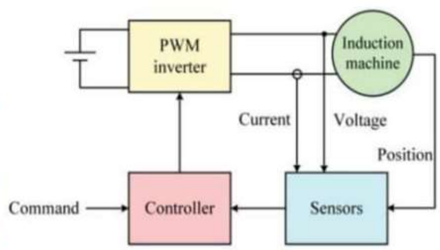
INDUCTION MOTOR DRIVES

The single-motor configuration of the induction motor drive has been widely adopted for commercial EVs.

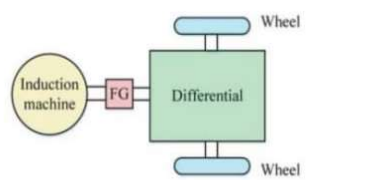
The single-motor configuration uses only one IM and one PWM inverter, which can minimize the corresponding size, weight, and cost. However, it needs a differential to adjust the relative speeds of the driving wheels for cornering.

In addition, it employs a fixed gear (FG) to reduce the motor speed to match with the wheel speed.

It should be noted that the high-speed design of IMs is widely adopted for EV propulsion because this design favors the reduction of machine size and weight, which are crucial factors for EVs.



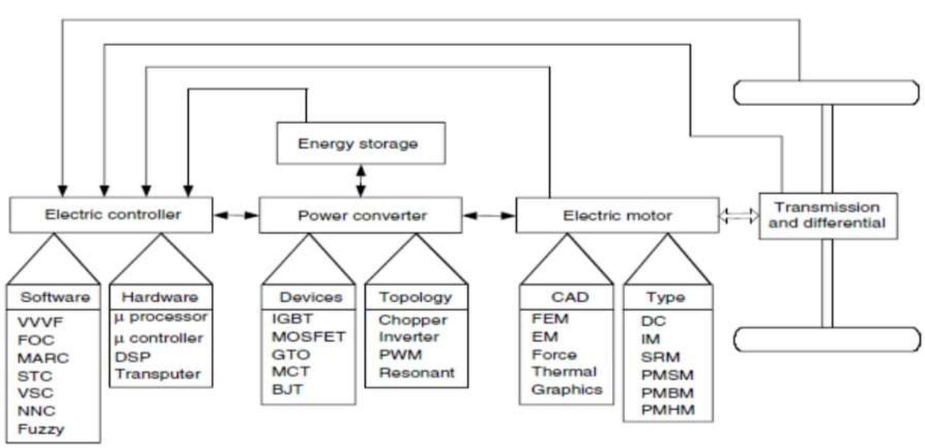
Basic configuration of induction motor drive



Single-motor configuration of induction motor drive for EVs

7	Explain the functional block diagram of an EV propulsion and hence discuss the various choices of electric propulsion for EV consideration.	10	CO4	L2

FUNCTIONAL BLOCK DIAGRAM OF A TYPICAL ELECTRIC PROPULSION SYSTEM



ELECTRIC PROPULSION SYSTEM

Electric propulsion system consists of

- **ELECTRIC MOTORS**

The electric motor converts the electric energy into mechanical energy to propel the vehicle, or, vice versa, to enable regenerative braking and/or to generate electricity for the purpose of charging the onboard energy storage.

- **POWER CONVERTERS**

Power converter is used to supply the electric motor with proper voltage and current.

- **ELECTRONIC CONTROLLERS**

The electronic controller commands the power converter by providing control signals to it, and then controls the operation of the electric motor to produce proper torque and speed, according to the command from the drive.

ELECTRIC PROPULSION SYSTEM

The Electronic controller used in EVs and HEVs has three functional units

The SENSOR which is used to translate measurable quantities such as current, voltage, temperature, speed, torque, and flux into electric signals through the interface circuitry. These signals are conditioned to the appropriate level before being fed into the PROCESSOR.

INTERFACE CIRCUITRY amplifies the processor output signals and generates the switching signals to drive power semiconductor devices of the power converter.

Factors to be considered while choosing an Electric propulsion systems for EVs and HEVs

Driver expectation

- Acceleration
- Maximum speed
- Climbing capability
- Braking
- Range

CHOICE OF ELECTRIC PROPULSION SYSTEMS FOR EVs AND HEVs

Vehicle constraints

- Vehicle type
- Vehicle Weight and Volume
- Payload.

The energy source

- Batteries
- Fuel cells
- Ultracapacitors
- Flywheels
- Hybrid sources