4th unit

Fuel cells :-

It is defined as an electrochemical cell that generates electrical energy from fuel via an electrochemical reaction.

⇒ Fuel cells require a continuous input of fuel and an oxidising agent (generally oxygen) in order to sustain the reactions that generate electricity.

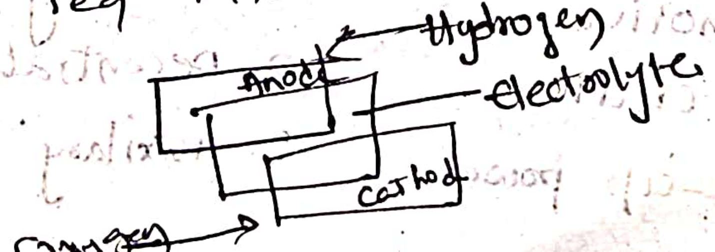
⇒ These cells continuously generate electricity until the supply of fuel and oxygen is cut-off.

Basic of fuel cell :-

⇒ An electrochemical device which converts the chemical energy of the fuel and an oxidant directly into electricity.

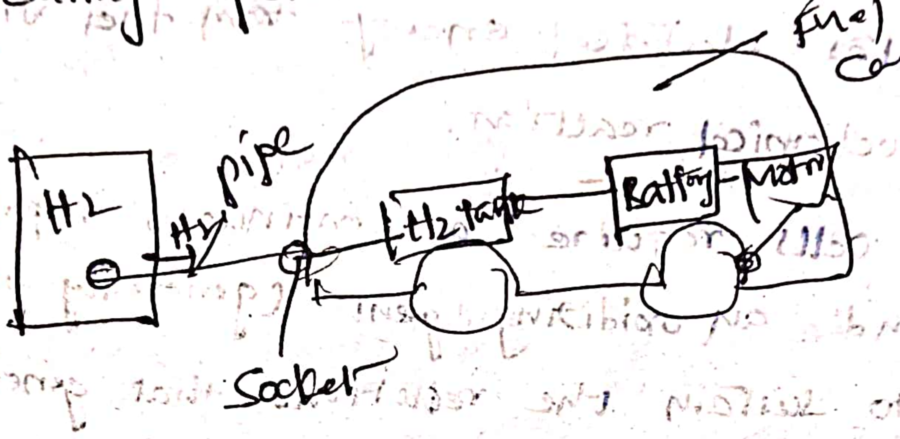
⇒ A single cell consists of an electrolyte layer in contact with a porous anode and cathode on either side.

⇒ The fuel (Hydrogen) is fed into the anode (-ve electrode) and an oxidant (oxygen) is fed into the cathode (+ve electrode)



Why Fuel cell is impressive for power generation?

=> less emission of and release of pollutant during operation



=> Higher conversion Energy

=> Fuel cell plant can be used as an decentralized power generation unit.

=> The heat generated can be easily removed and discharged to the atmosphere or used locally hence no additional coolant is Required

=> Fuel Cells plants are compact and Require less space

=> Fuel cell plant can be used efficiently at varying load conditions (50% to 100%)

Applications of Fuel cells :-

1. portable Electronics
2. Automotive
3. space craft
4. Back-up power
5. Submarine
6. Military & Aerospace
7. Decentralized power
8. Auxilary power

Classifications of FC :-

1. Based on the types of Fuel and oxidant
2. Based on type of Electrolyte
3. Based on the operating temperature

1. Based on the types of Fuel and oxidant :-

- ⇒ Hydrogen (pure) + oxygen (pure)
- ⇒ Hydrogen rich ~~air~~ gas + air
- ⇒ Hydrazine + oxygen peroxide / Hydrogen peroxide
- ⇒ Ammonia + air
- ⇒ synthesis gas + air
- ⇒ Hydrocarbon (gas) + air
- ⇒ Hydrogen (liquid) + air

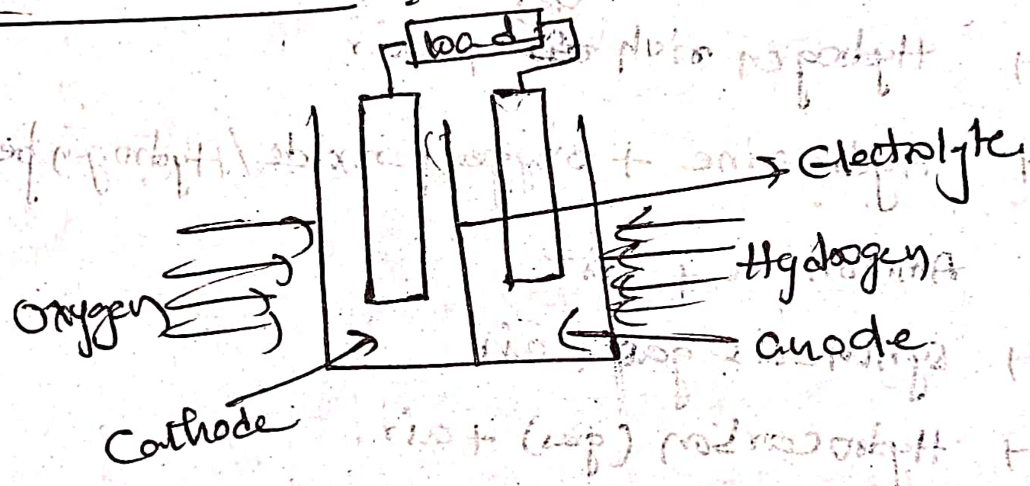
2. Based on the type of Electrolyte :-

- ⇒ phosphoric acid Fuel cell (PAFC)
- ⇒ Alkaline Fuel cell
- ⇒ polymer electrolytic membrane fuel cell (PEMFC)
- ⇒ solid polymer Fuel cell of proton Exchange membrane
- ⇒ Molten Carbonate Fuel cell
- ⇒ solid oxide Fuel cell

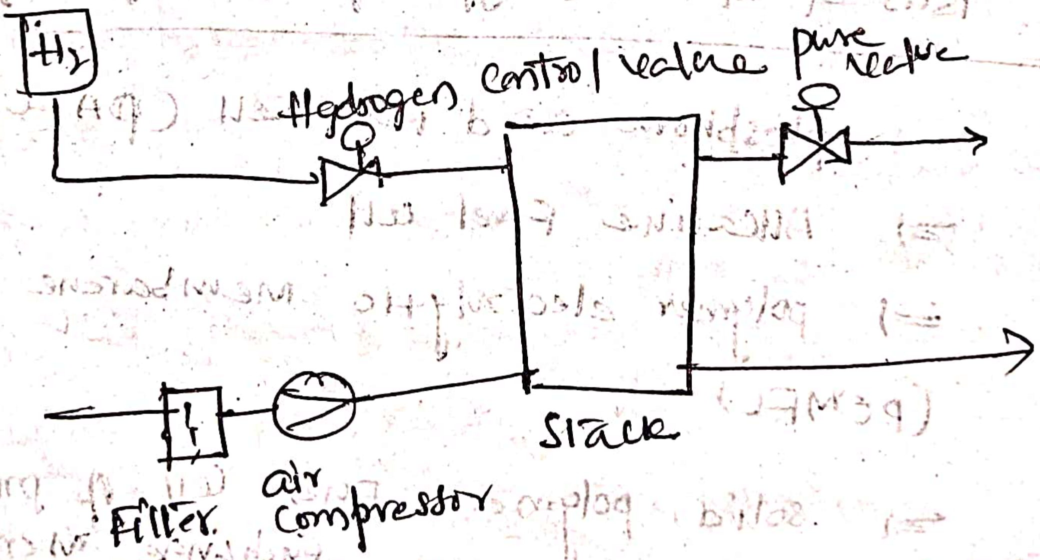
Based on the operating temperature :-

* low temperature ($< 180^\circ C$)
* Medium temperature ($180^\circ C - 250^\circ C$)
* Highly temperature ($250^\circ C - 800^\circ C$)
* Very high temperature ($800^\circ C - 1100^\circ C$)

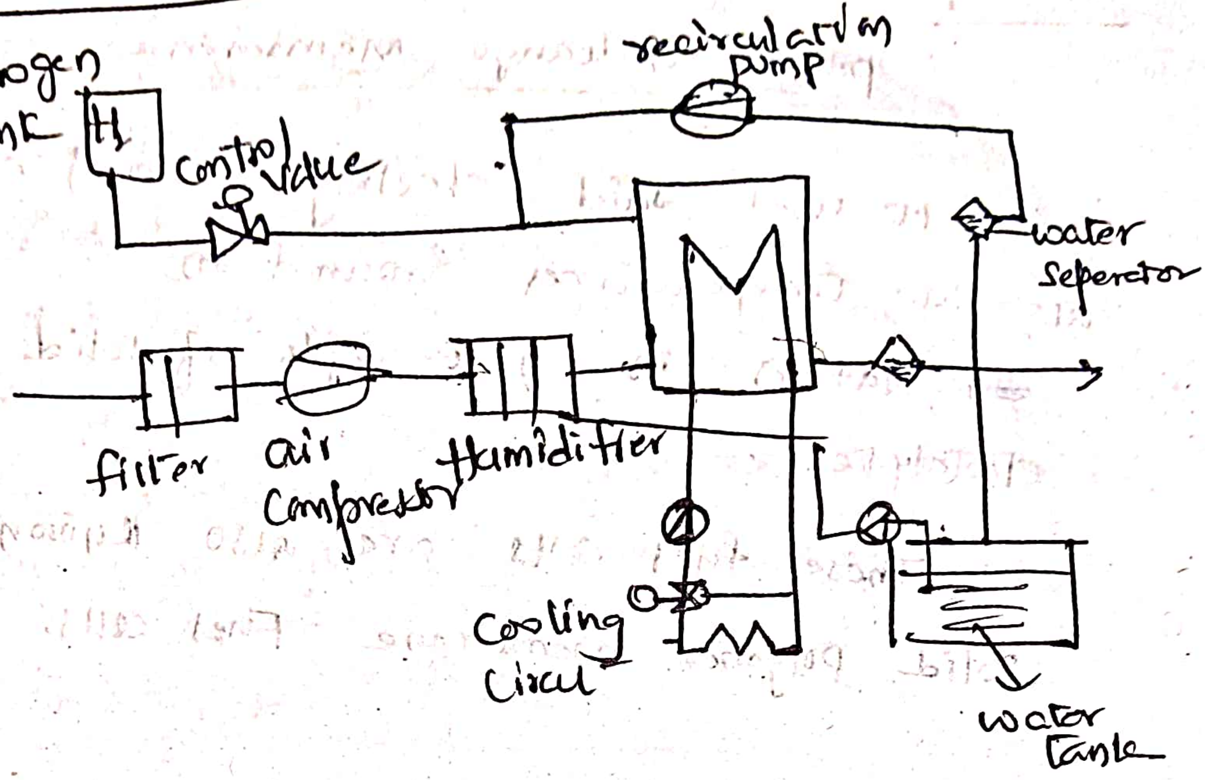
Fuel cell model :-



Basic Fuel cell system :-



Advanced Fuel Cell :-



Gibbs free energy :-

⇒ This is defined as the energy available to do the external work, neglecting any work done by changes in pressure and/or volume.

Entropy S :- The Measure of system's thermal energy per unit temperature that is unavailable for doing useful work

Enthalphy H :- It is Gibbs energy + Entropy

⇒ $H = G + S$

⇒ $\boxed{G = H - S}$

Example :-

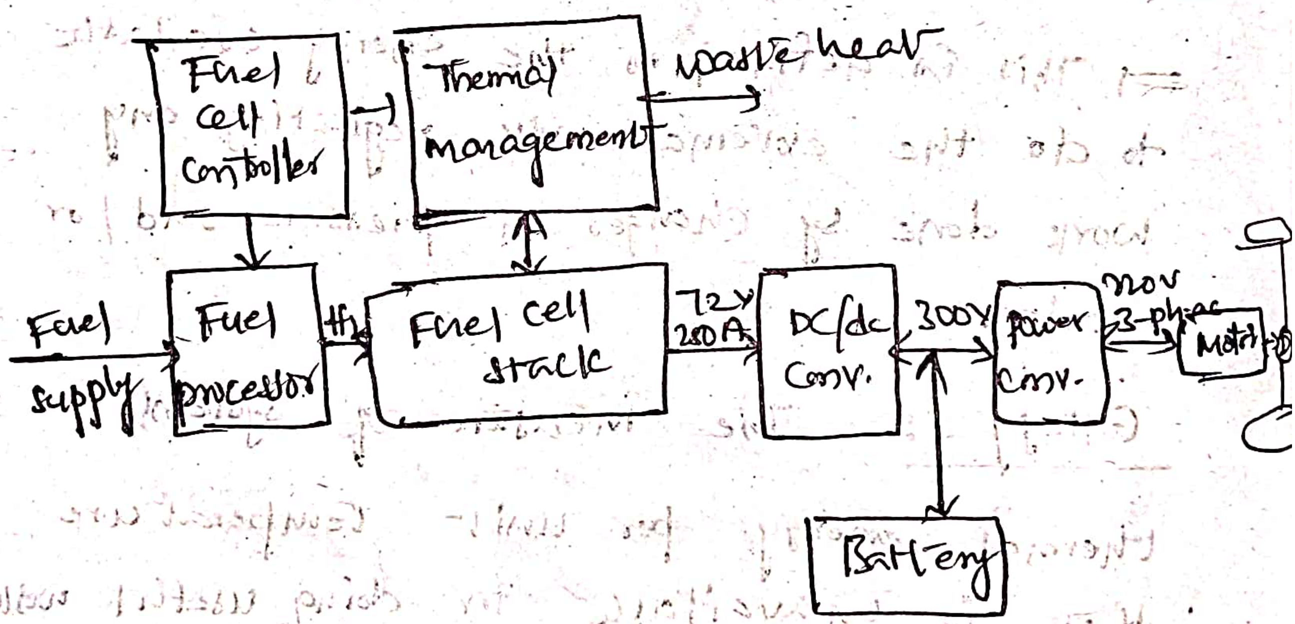
Proton Exchange Membrane

⇒ It uses solid electrolytes and operate at low temperatures around 80.

⇒ Nafion is an example of solid polymer electrolyte.

⇒ These fuel cells are also known as solid polymer membrane Fuel cells.

Fuel-cell-based EV

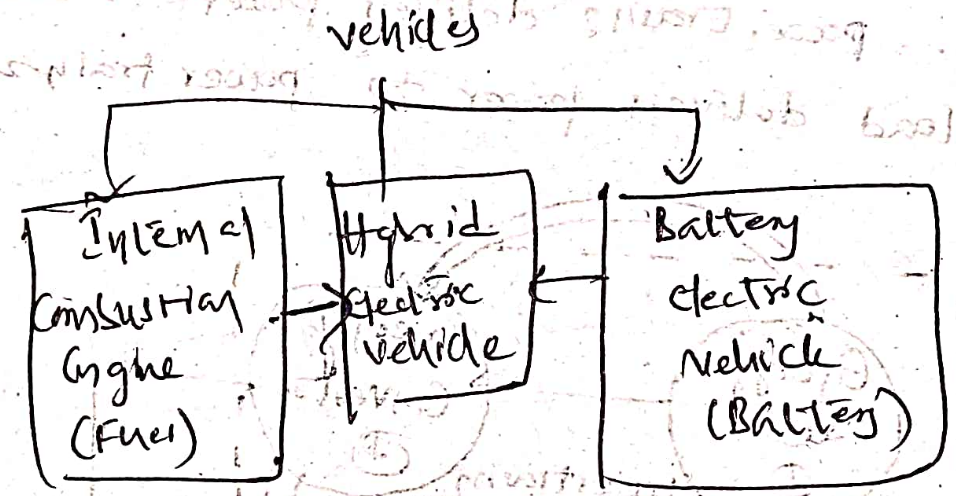


Hybrid electric vehicle :-

⇒ The term hybrid vehicle refers to a vehicle with at least two source of power

⇒ one source of power by motor

⇒ other source of motive power comes from different technologies, it is provided as an internal combustion engine to run either on gasoline / diesel fuel.



HEV configurations :-

⇒ There are various possible ways of combining the powerflow to meet the driving requirements are :-

1. powertrain 1 directly delivers power
2. power train 2 ~~directly~~ alone delivers power
3. Both power train 1 and power train 2 deliver power to load at same time
4. powertrain 2 obtains power from load (Regenerative breaking)

5. powertrain 2 obtain power from power train 1

6. power train 2 obtain power from powertrain 1 and load at the same time

7. powertrain 1 delivers power simultaneously to load, to powertrain 2

8. powertrain 1 delivers power to powertrain2 and powertrain2 delivers power to load

9. powertrain 2 delivers power to load and load delivers power to powertrain 2

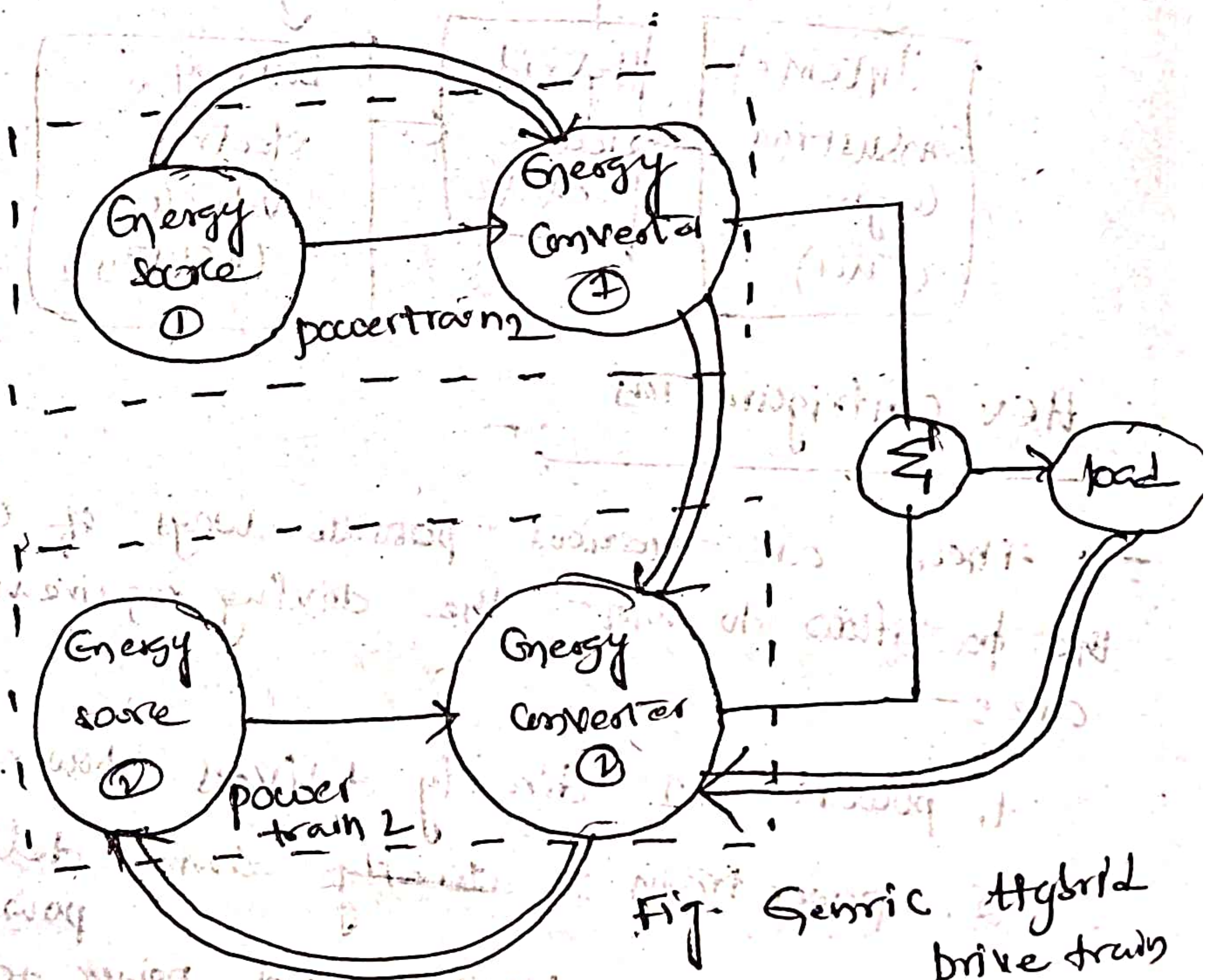


Fig. Generic Hybrid Drive train

⟶ power flow while propelling

⟹ power flow while charging power train

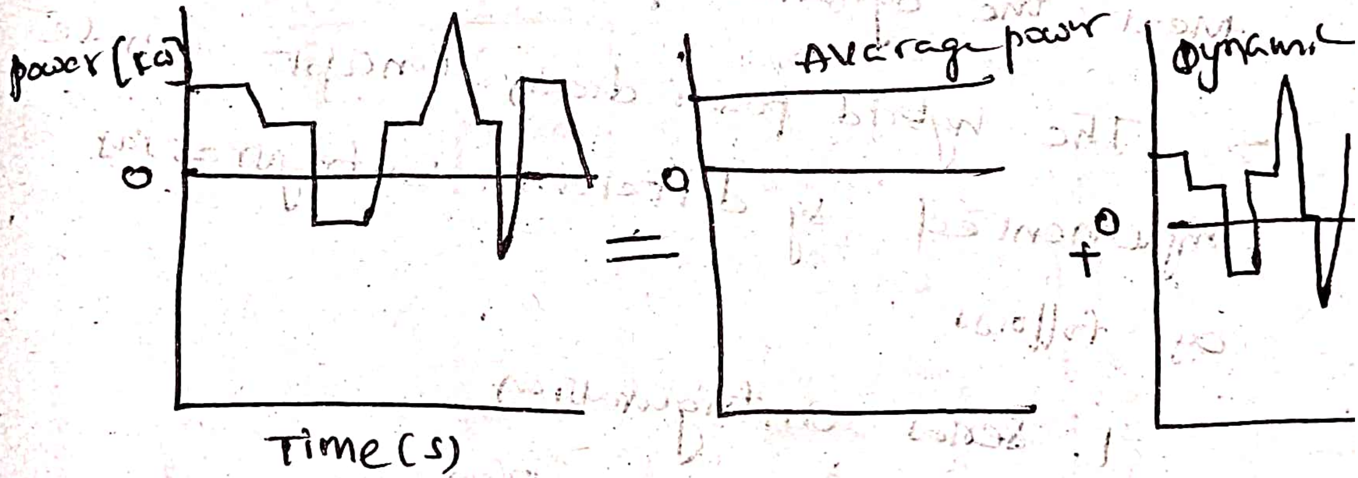
⇒ The load power of a vehicle varies randomly in actual operation due to frequent acceleration, deacceleration and climbing up and down the grades

The load power can be decomposed into two parts:-

1. steady power (power with constant)

2. dynamic power (The power whose average value is zero)

load power decomposition :-



⇒ In HEV, one powertrain favors steady state operation, such as an ICE / Fuel cell

⇒ The other powertrain in the HEV is used to supply the dynamic power.

⇒ The total energy output from the dynamic powertrain will be zero in the whole driving cycle.

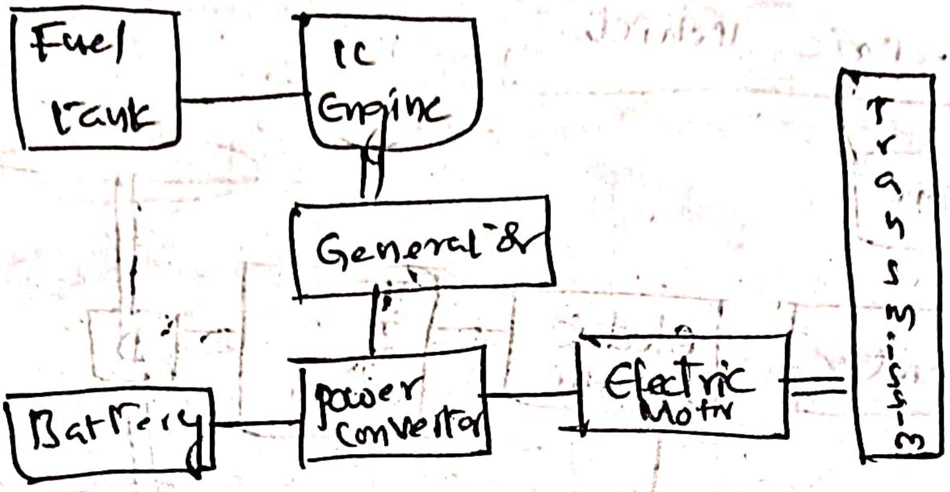
⇒ Generally, electric motor are used to meet the dynamic power demand.

⇒ The hybrid power drain concept can be implemented by different configurations as follows

1. Series configuration
2. parallel configuration
3. Series - parallel configuration

1. Series configuration :-

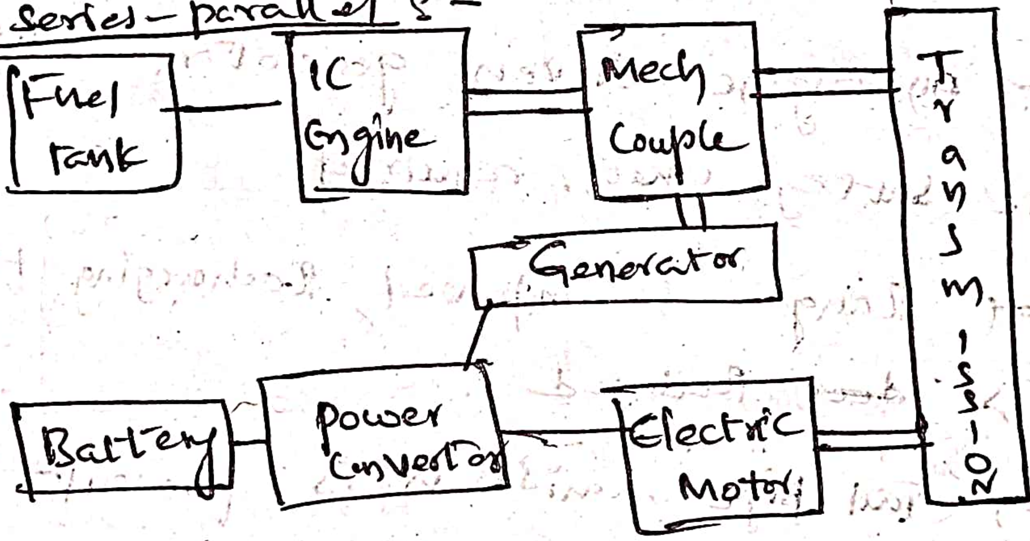
⇒ It is to couple the ICE with the generator to produce electricity for pure electric propulsion



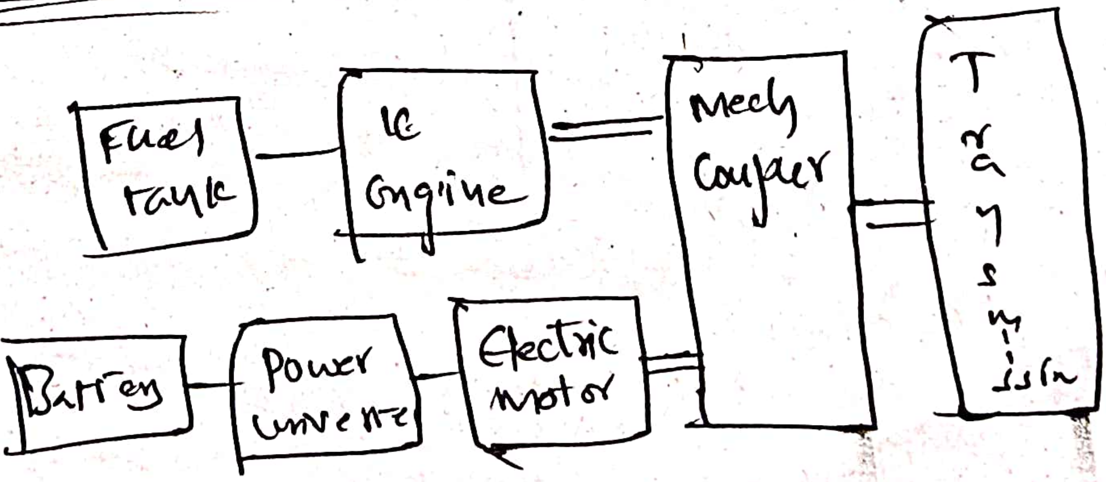
2. parallel configuration :-

→ To couple both the ICE and electric motor with the transmission via the same drive shaft to propel the vehicle

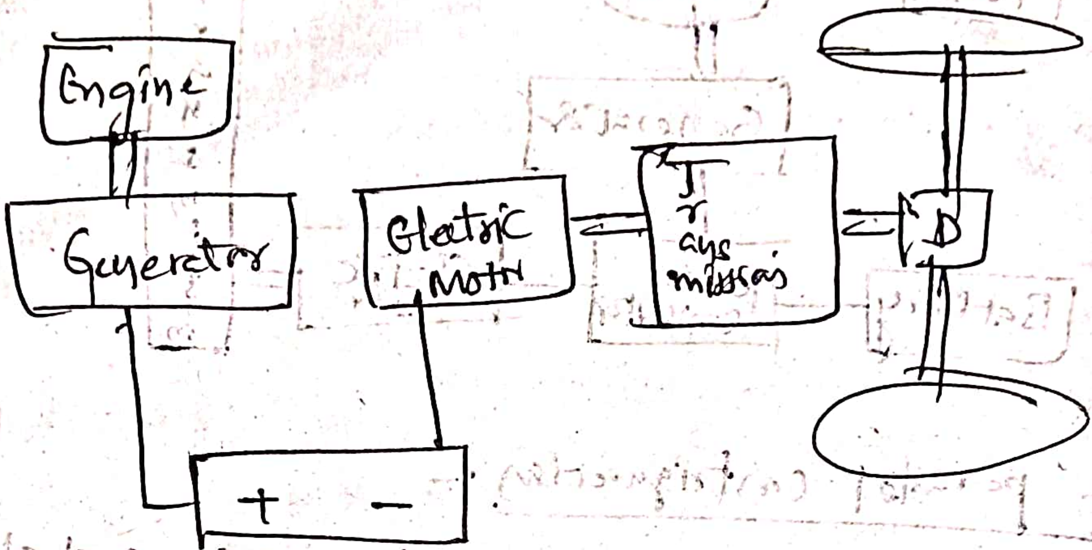
3. Series-parallel :-



3. ~~Series - parallel~~ :-



pure electric vehicle :-



Electric vehicle with Range Extender :-

→ An engine driven generator recharging the battery when required

→ Range is improved, Recharging time is ~~deer~~ Reduced

→ Tail pipe emissions is present

Series Hybrid	Series - parallel
→ Flexibility of location of engine-generator set.	→ Complexity in the location of engine-generator set
→ simplicity of drive train	→ complexity of drive train.
→ Required three propulsion components ICE, generator, motor	→ Requires two propulsion system 1. ICE 2. generator/motor
→ The motor must be designed for the maximum sustained power	→ The motor/generator may still be rated to half the maximum power or even smaller
→ Example:- Cadillac ELR	→ Example:- Toyota prius

Brake specific ~~Specific~~ Fuel Consumption :-

⇒ Brake Specific Fuel Consumption

$$= \frac{\text{Fuel Mass flow rate } (\dot{m}_f)}{\text{Brake power (BP)}}$$

Brake power = power at the crankshaft which is given by,

$$\boxed{Bp = \frac{2\pi NT}{60}}$$

T = Torque at crankshaft,

N = RPM of the crank shaft,

⇒ The SI unit is kg/kWh.

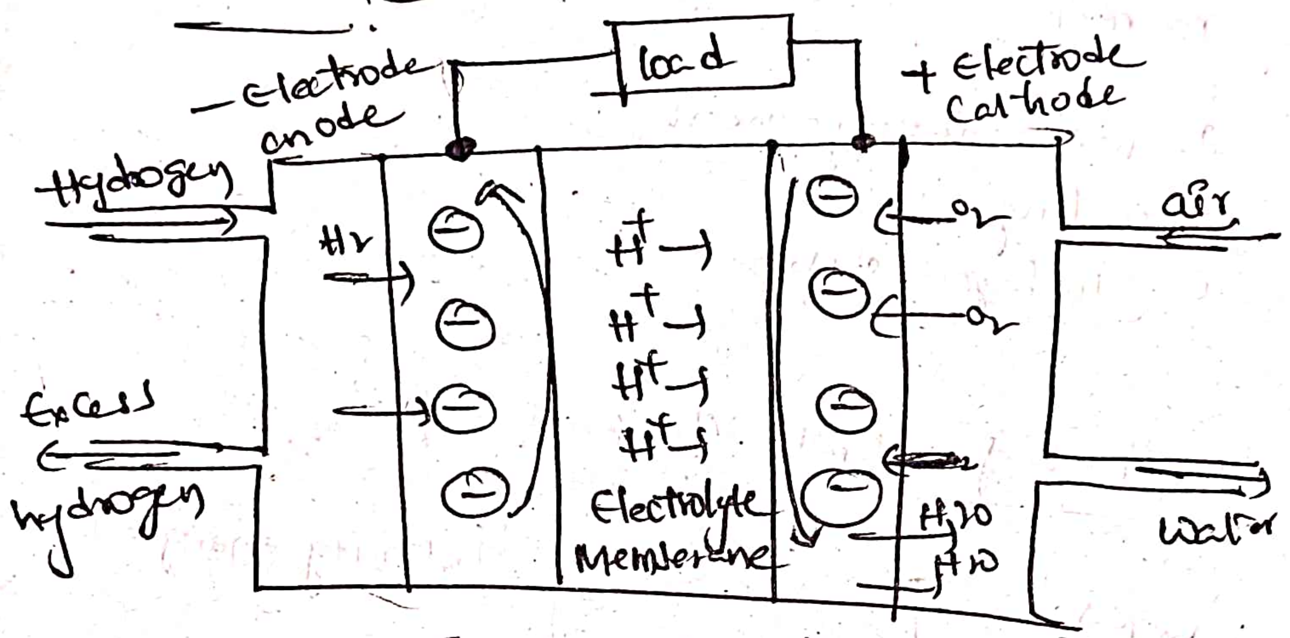
⇒ It says how efficiency the particular fuel gets converted into brake power.

⇒ The low value of BSFC says that the engine requires less amount of fuel for the generation of the unit amount of power.

⇒ It is helpful to compare different automobile to convert fuel into brake power.

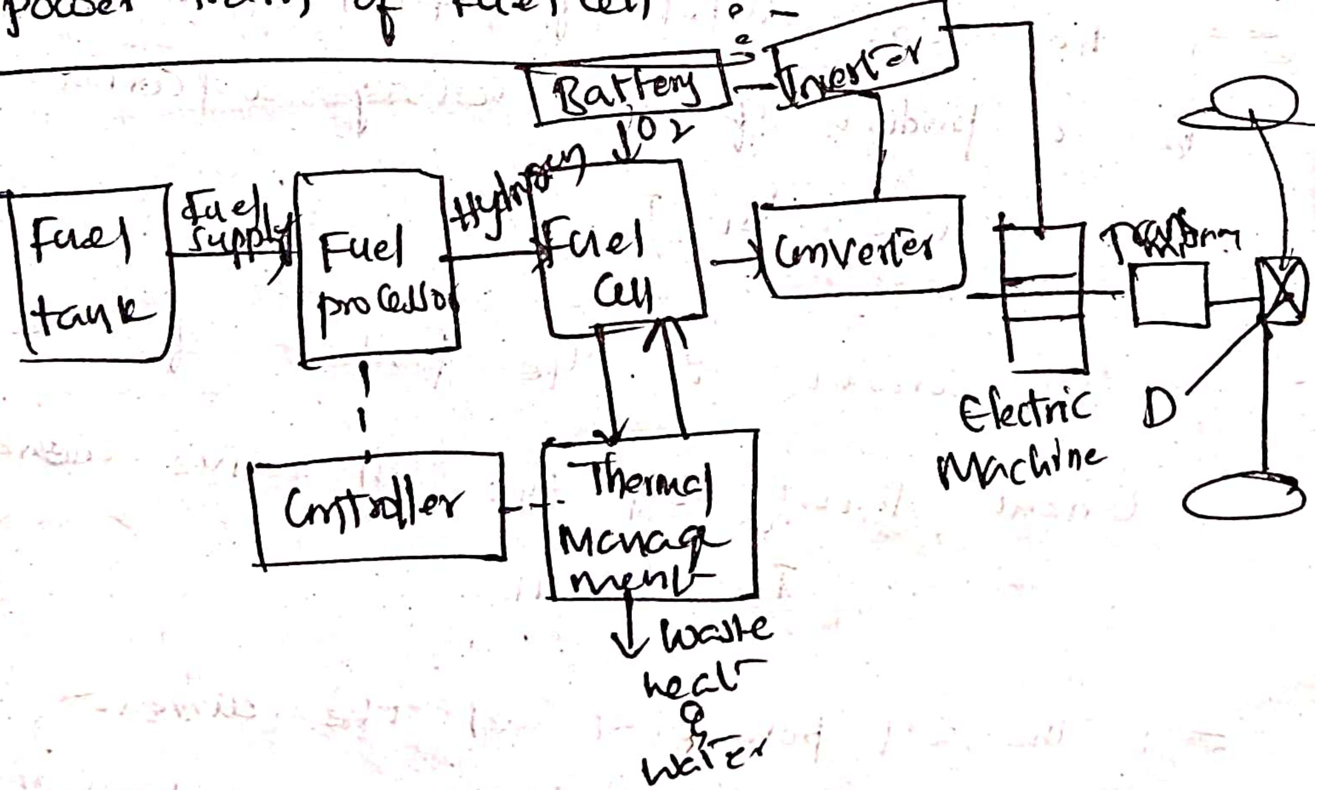
Fuel cells :-

(i) proton - exchange membrane Fuel Cell :-



In place of H^+ put OH^- and change → to ← makes alkaline Fuel cell

power train of Fuel cell :-

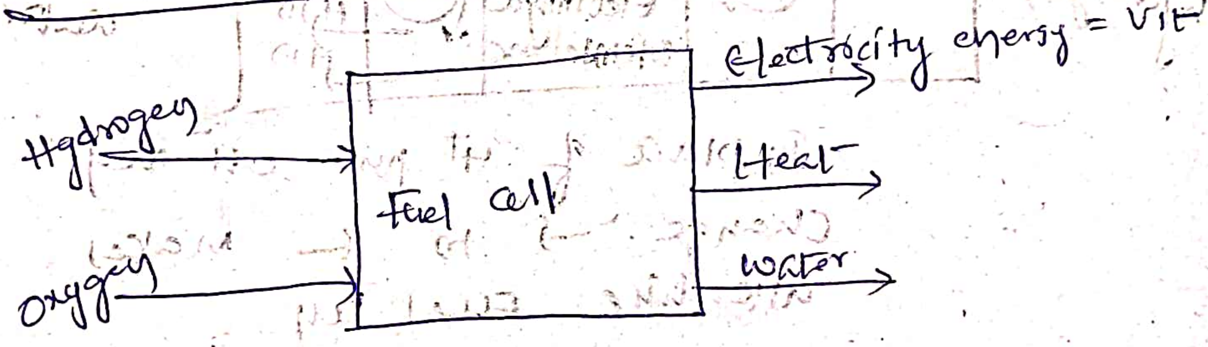


5th unit

Main Issues in the Fuel cell :-

1. cost :- Expensive than IC Engine
2. water management
3. cooling
4. Hydrogen supply

Input and output of Fuel cell :-



⇒ The power output of a Fuel cell stack is a product of stack voltage and current

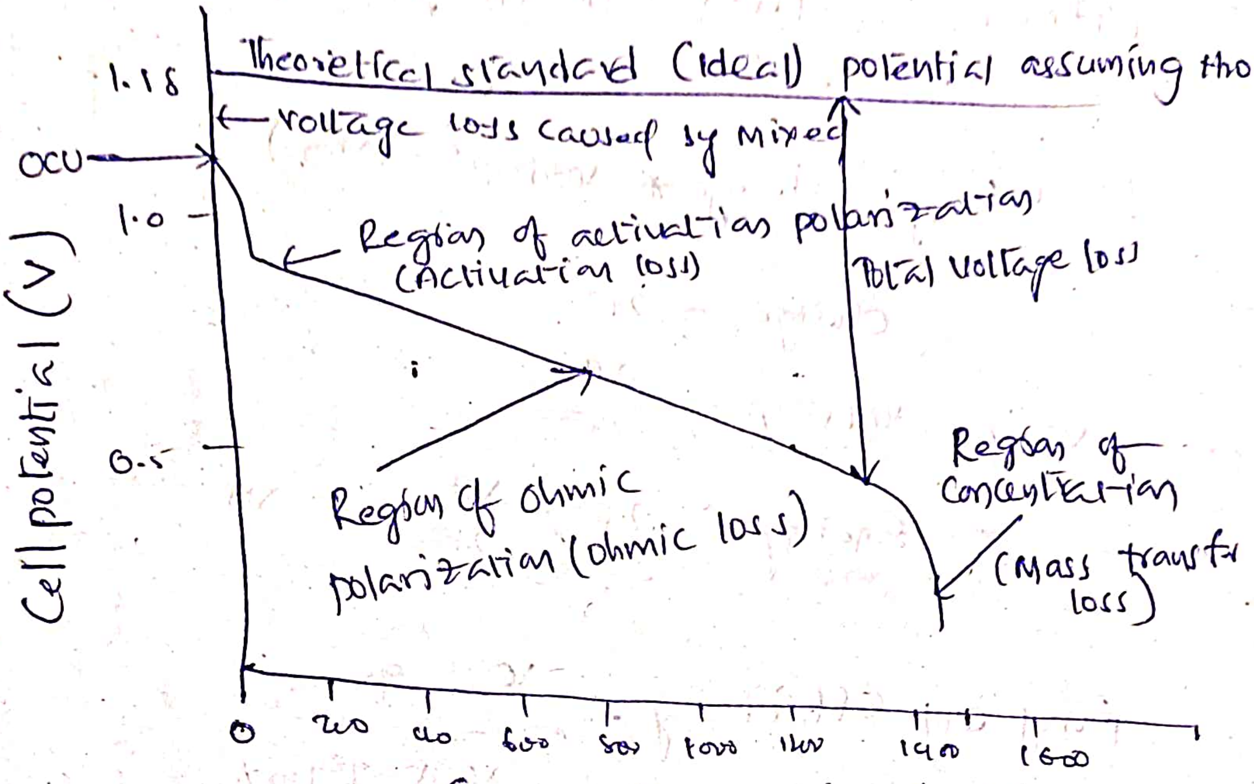
$$W_{FC} = V_{st} \cdot I$$

⇒ The current is the product of the current density and the cell active area

$$I = i \cdot A_{cell}$$

⇒ The cell potential and the current density and related by the polarization curve

$$V_{cell} = f(i)$$



Typical polarization curve for a PEM fuel cell stack

· uses 0.6V to 0.7V at nomical power

Three Main reasons for this loss voltage :-

1. activation Energy - voltage drop

2. The Resistance of the electrolyte and the electrodes causes a voltage drop.

3. Following of ohm's law causes steady fall in voltage. It is called ohmic ~~~~ voltage loss

4. concentration voltage loss

~~~~ geting depleted oxygen at high ~~~~ current
~~~~

Efficiency & Fuel cell voltage:-

Energy = charge × voltage (V_{100})

Charge = 2F

$V_{100\%}$ = voltage = $\frac{\Delta H}{2F}$

$\Rightarrow$ Energy = $\cancel{2F} \times \frac{\Delta H}{\cancel{2F}} = \Delta H$

Fuel cell Efficiency = $\frac{voltage_c}{voltage_{100\%}}$

$= \frac{V_c}{\frac{\Delta H}{2F}}$

$= \frac{V_c \times 2F}{\Delta H}$

$\Rightarrow$ Maximum voltage of a Fuel cell

is

$$\boxed{V_{max} = \frac{V_c \times 2F}{\Delta G}}$$

$$\Delta V = \frac{RT}{4F} \ln\left(\frac{P_2}{P_1}\right)$$

$$= \frac{RT}{4F} 2.303 \log\left(\frac{P_2}{P_1}\right)$$

Sizing of Fuel Cell :-

Power capacity of the PPS : $P_{pps} = \frac{P_{motor}}{\eta_{motor}} - P_{fc}$.

Energy capacity of the PPS :-

$$E = \int (P_{pps-charge} - P_{pps-discharge})\, dt_i$$

$$CE = \frac{\Delta E_{max}}{C_P}$$