MODULE - 4

Hybrid Vehicle

The hybrid electric vehicle concept can be implemented by different configuration as follows.

- Series Configuration
- Parallel Configuration
- Series- Parallel Configuration
- Complex Configuration.

Series Hybrid System :

- In case of series hybrid system the mechanical output is first converted into electricity using a generator.
- The converted electricity either charges the battery or can bypass the battery to propel the wheels via the motor and mechanical transmission.
- Conceptually, it is an ICE assited Electric vehicle (EV).

The advantages of the series hybrid are

- Mechanical decoupling between the ICE and driven wheels allows the IC engine operating at its very narrow optimal region as shown in fig (4)
- nearly ideal torque-speed characteristics of electric motor make multigear transmission unnecessary.

The disadvantages of the series hybrid are:

- The energy is converted twice (mechanical to electrical and then to mechanical) and this reducess the overall efficiency.
- Two electric machines are needed and a big traction motor is required because it is the only torque source of the driven wheels

* The series hybrid is used in heavy commercial vehicles the reason behind it is to have enough space requirements for the bulky engine /generator system.

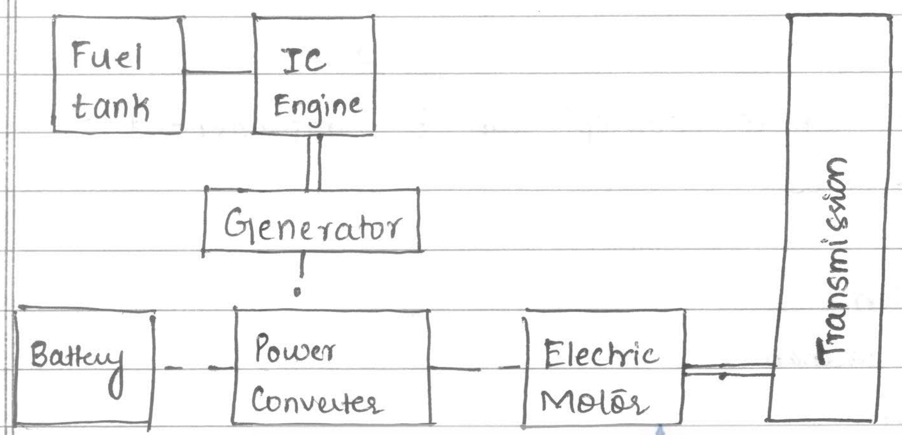

fig (4) Series Hybrid.

- Parallel Hybrid System
- The parallel HEV (fig 5) allows both ICE and electric motor (EM) to deliver power to drive the wheels. Since both the ICE and EM are coupled to the drive shaft of the wheel via two clutches, the propulsion power may be supplied by ICE alone, by EM only or both ICE and EM.
- The EM can be used as a generator to charge the battery by regenerative braking or absorbing power from the ICE when its output is greater than that required to drive the wheels.

The advantages of parallel hybrid are.

- Both engine and electric motor directly supply torques to the driven wheels and no energy form conversion occurs, hence energy loss is less.
- Compactness due to no need of the generator and smaller traction motor

Disadvantages of Parallel Hybrid system

- mechanical coupling between the engines and the driven wheels, thus the engine operating points cannot be fixed in a narrow speed region
- The mechanical configuration and the control strategy are complex compared to series hybrid system.

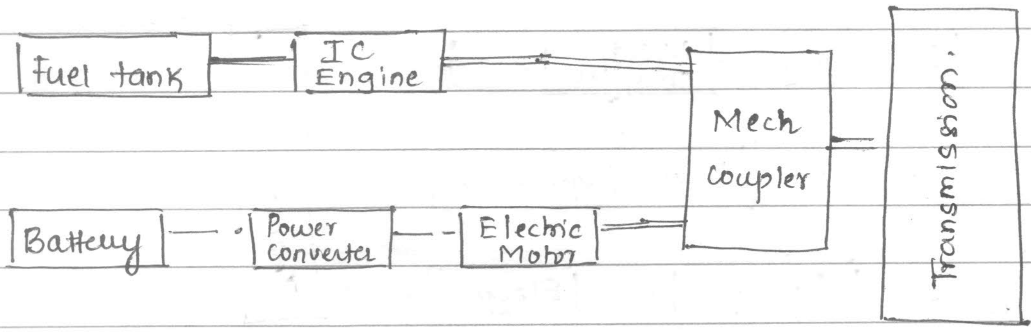

fig (5) Parallel hybrid.

Series Parallel System.

In this series-parallel hybrid (fig 6) the configuration incorporates the features of both series and parallel HEV's However, this configuration needs an additional electric machine and a planetary gear unit making the control complex.

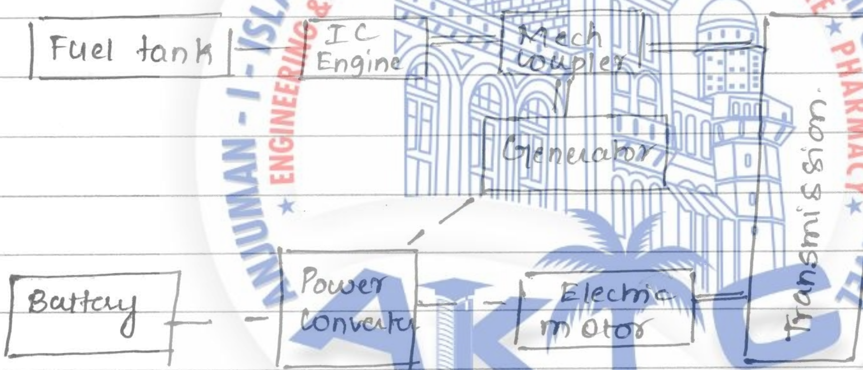

fig (6) Series Parallel Hybrid System

Complex Hybrid System

- The complex hybrid system fig (7) involves a complex configuration which cannot be classified into the above three kinds. which are series hybrid system, parallel hybrid system and series-parallel hybrid system.
- The complex hybrid is similar to the series-parallel hybrid since the generator and electric motor is both electric machines. However, the key difference is due to the bi-directional power flow of the electric motor in complex hybrid and the unidirectional power flow of the generator in the series-parallel hybrid.
- The major disadvantage of complex hybrid is higher complexity.

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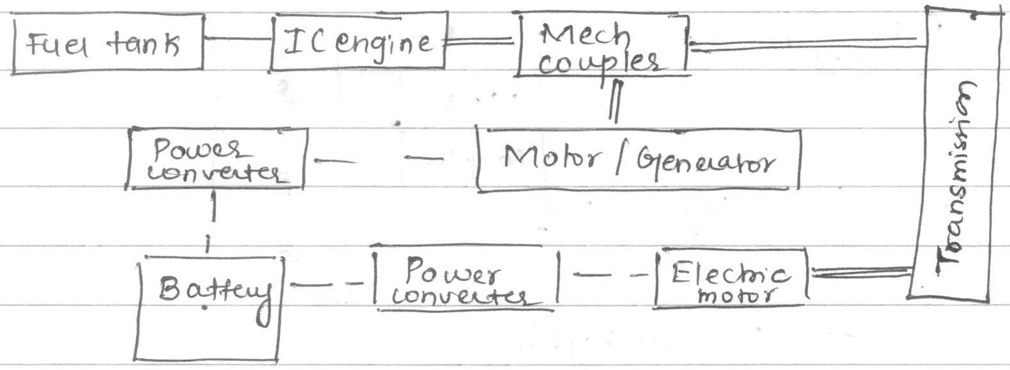

fig (7) complex hybrid.

POWER FLOW IN HEV's

Introduction

The following topics are covered in this lecture

- Power flow control
- Power flow control in Series Hybrid
- Power flow Control in Parallel Hybrid
- Power flow control in Series - Parallel Hybrid.

Power flow Control.

Due to the variations in HEV configurations, different power control strategies are necessary to regulate the power flow from different components. All the control strategies aim to satisfy the following goals:

- maximum fuel efficiency
- minimum emissions.
- minimum system costs
- good driving performance.

The design of power control strategies for HEV's involve different considerations such as:

- **Optimal ICE operating point:**

  The optimal operating point on the torque speed plane of the ICE can be based on maximization of fuel economy, the minimization of emissions or a compromise between fuel economy and emissions.

- **Optimal ICE Operating Line:**

  In case the ICE needs to deliver different power demands, the corresponding optimal operating points constitute an optimal operating line.

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- **Safe battery Voltage :**
  The battery voltage may be significantly altered during discharging, generator charging or regenerative charging. This battery voltage should not exceed the maximum voltage limit nor should it fall below the minimum voltage limit.

Power flow Control in Series Hybrid.

In the series hybrid system there are four operating modes based on the power flow.

- Mode 1 : During startup (fig 1a), normal driving or acceleration of the series HEV, both the ICE and battery delives electric energy to the power converter which then drives the electric motor and hence the wheels via transmission.

fig 1(a) normal driving or acceleration

- Mode 2 : At light load (fig 1b), the ICE output is greater than that required to drive the wheels. Hence, a fraction of the generated electrical energy is used to charge the battery. The charging of the battery takes place till the battery capacity reaches a proper level.

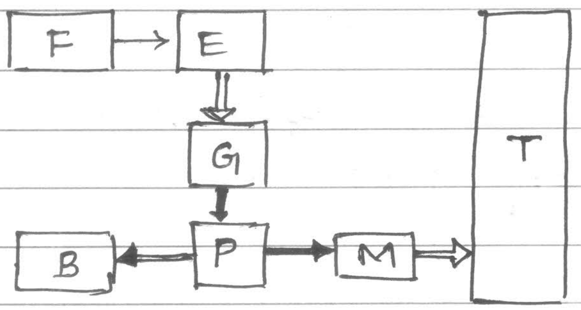

fig 1(b)

- Mode 3: During braking or deceleration (opposite of acceleration It is the rate at which an object slows down). fig (1c), the electric motor acts as a generator, which converts kinetic energy of the wheels into electricity and this is used to charge the battery.

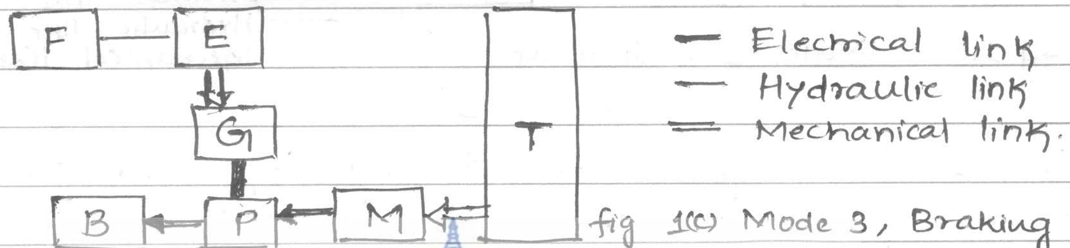

fig 1(c) Mode 3, Braking or decelerat

B: Battery G: Generator T: Transmission (including brakes, clutches & gears)
E: ICE M: Motor
F: Fuel tank P: Power Converter

- Mode 4: The battery can also be charged by the ICE via the generator even when the vehicle comes to a complete stop (fig 1d)

fig 1(d) Mode 4, vehicle at stop

Power Flow Control in Parallel Hybrid.

The parallel hybrid system has 4 modes of operation. are

- Mode 1: During start up or full throttle acceleration (it is a mechanism which allows fluid to flow without any obstruction) both the ICE and EM share the required power to propel the vehicle. Typically, the relative distribution between the ICE and electric motor is 80-20%.

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B: Battery G: Generator
E: ICE M: Motor
F: Fuel tank P: Power Converter
T: Transmission (including brakes, clutches & gears)
— Electrical link
— Hydraulic link
═ Mechanical link.

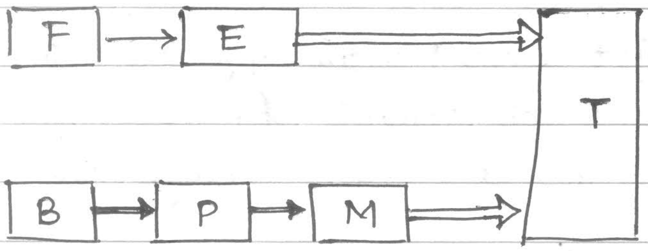

fig 2a Mode 1, Start up

- Mode 2 : During normal driving (fig 2b), the required traction power is supplied by the ICE only and the EM remains in off mode.

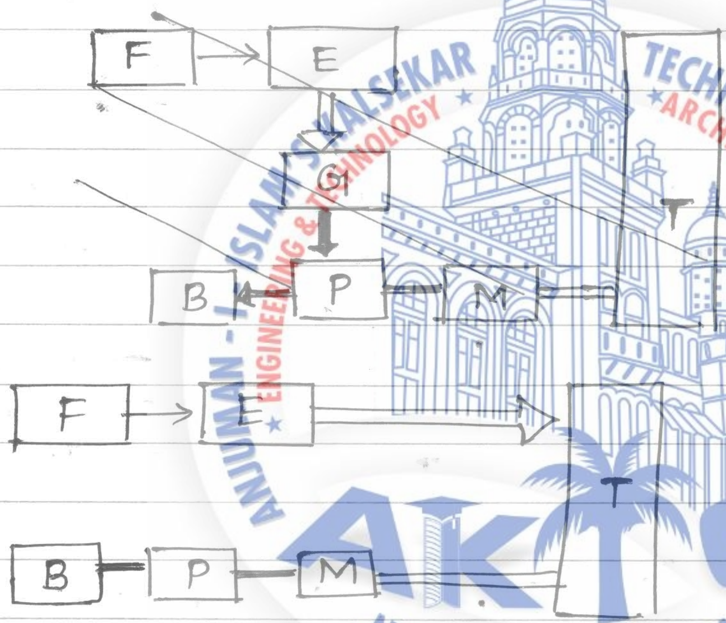

fig 2b Mode 2, normal driving

- Mode 3 : During braking or deceleration fig 2c, the EM acts as a generator to charge the battery via the power converter.

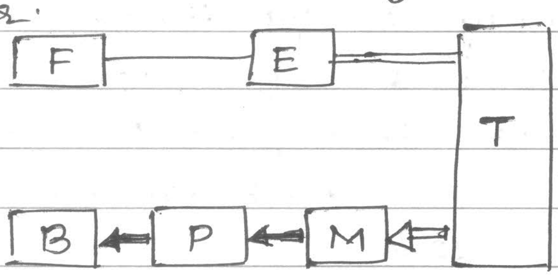

fig 2c Mode 3, braking or deceleration.

~~Mode 4 : During normal braking or deceleration~~

Mode 4: Under light load condition (fig 2d), the traction power is delivered by the ICE and the ICE also charges the battery via the EM

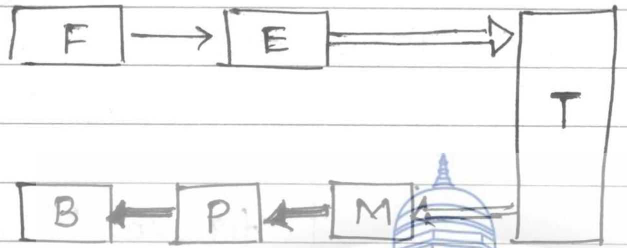

fig 2d Mode 4 light load.

Power flow Control Series-Parallel Hybrid.

The series-parallel hybrid system involves the features of series and parallel hybrid systems. Hence, a number of operation modes are feasible. Therefore, these hybrid systems are classified in 2 categories.

The various operating modes of ICE dominated system are:

Mode 1: At start up (fig 3a), the battery only provides the necessary power to propel the vehicle and the ICE remains in off mode.

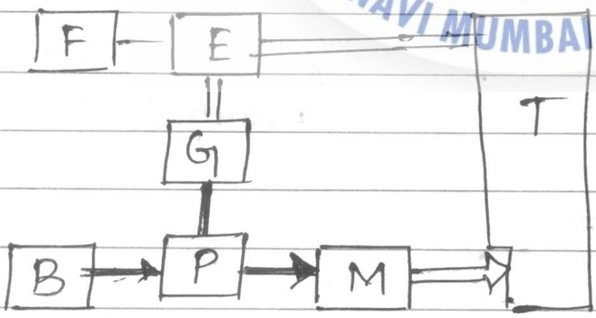

fig 3a Mode 1 start up

B: Battery. F: Fuel tank
E: ICE G: Generator
M: Motor P: Power converter
T: Transmission (including brakes, clutches and gears)

▬ Electrical link
— Hydraulic link
═ Mechanical link.

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- ~~Mode 2 : During full throttle acceleration (fig 3b) the req. traction power is provided by the ICE and only EM remains in the off state.~~

- Mode 2 : During full throttle acceleration (fig 3b) both the ICE and the EM share the required traction power.

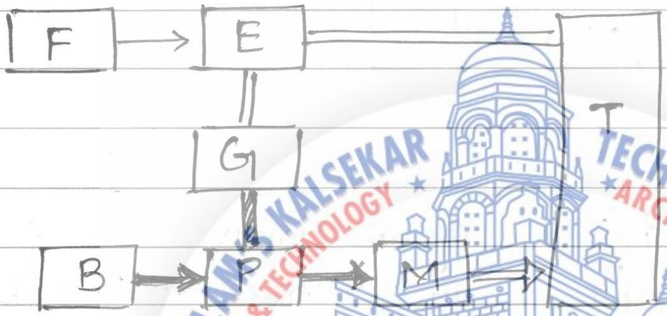

fig 3b Mode 2
Acceleration (1)

- Mode 3 : During normal driving (fig 3c) the required traction power is provided by the ICE only and the EM remains in the off state

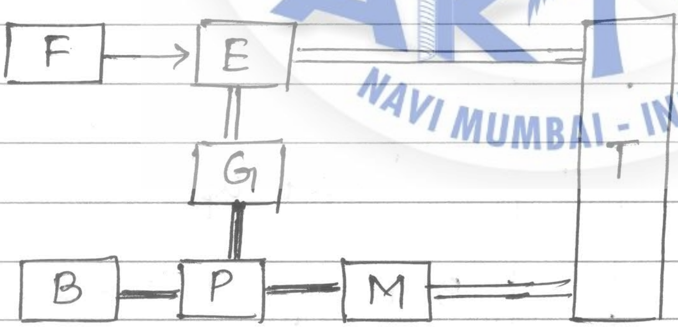

fig 3c Mode 3
Normal drive.

- Mode 4 : During normal braking or deceleration (fig 3d) the EM acts as a generator to charge the battery.

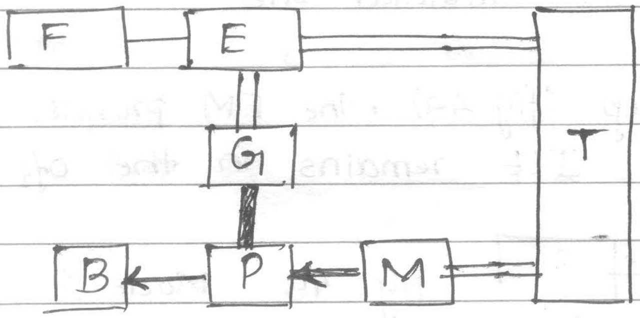

fig (3d) Mode 4
Braking or deceleration

- Mode 5 : To charge the battery during driving (fig 3e) the ICE delivers the required traction power and also changes the battery. In this mode the EM acts as a generator.

fig (3e) Mode 5
Battery charging during driving.

- Mode 6 : When the vehicle is a stand still (fig 3f) the ICE can deliver power to Change the battery via the EM

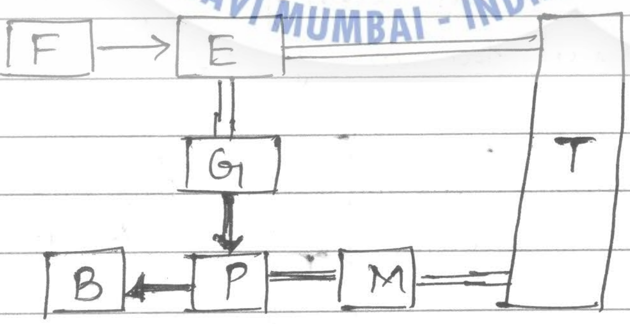

fig (3f) Mode 6
Battery charging during stand still.

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The operating modes of EM dominated are.

- Mode 1 : During startup (fig 4a), the EM provides the traction power and the ICE remains in the off state.

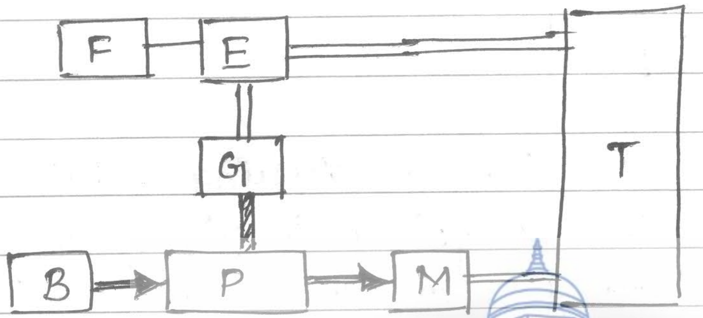

fig 4a Mode 1
start up.

- Mode 2 : During full throttle (fig 4b) both the ICE & EM provide the traction power

fig 4(b) Mode 2
Acceleration.

- Mode 3 : During normal driving (fig 4 c) both the ICE and EM provide the traction power

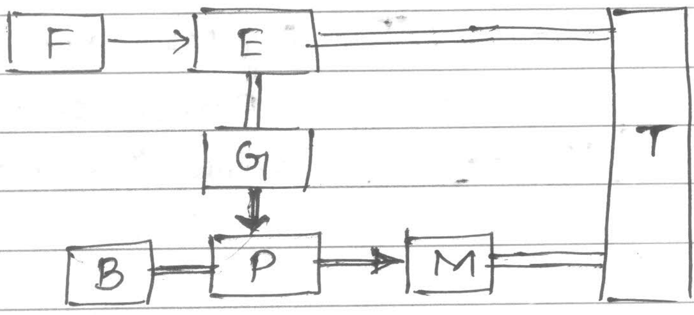

fig 4(c) Mode 3
Normal drive.

- Mode 4 : During braking or deceleration (fig 4d), the EM acts a generator to charge the battery.

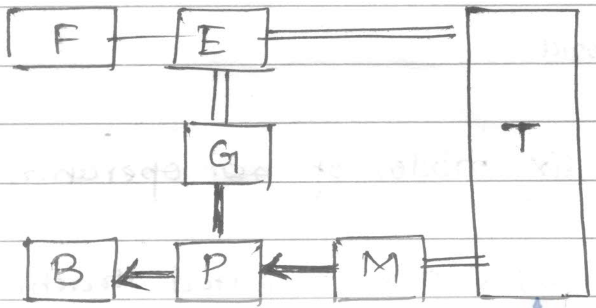

fig 4d Mode 4
Beaking or deceleration

- Mode 5 : To charge the battery during driving (fig 4e) the ICE delivers the required traction power and also charges the battery. The EM acts as a generator

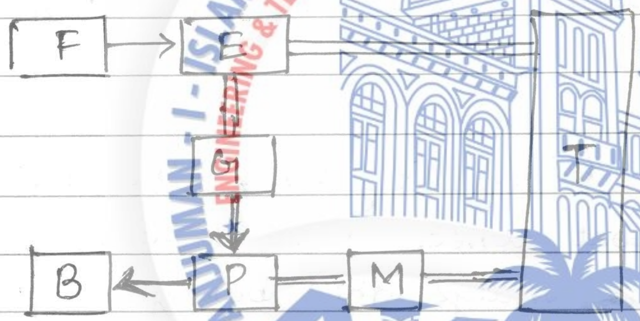

fig 4e Mode 5
Battery charging during driving.

- Mode 6 : When the vehicle is at the stand still (fig 4f) the ICE can deliver power to charge the battery via the EM

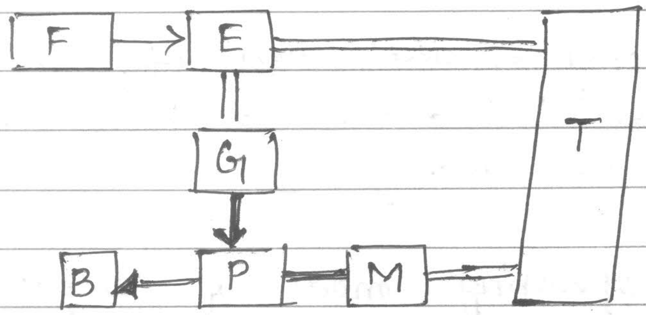

fig.(4f) Mode 6
Battery charging during stand still

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Power Flow Control Complex Hybrid Control

The complex hybrid vehicle configurations are of 2 types

- Front hybrid rear electric
- front electric and rear hybrid.

Both the configurations have six modes of operation:

- Mode 1: During startup (fig 5a), the required traction power is delivered by the EMs and the engine is in off mode.
- Mode 2: During full throttle acceleration (fig 5b) both the ICE and the front wheel EM deliver the power to the front wheel and the second EM deliver the power to the rear wheel.
- Mode 3: During normal driving (fig 5c), the ICE delivers power to propel the front wheel and to drive the first EM as a generator to charge the battery.
- Mode 4: During driving at light load (fig 5d) first EM delivers the required traction power to the front wheel. The second EM and the ICE are in off state.
- Mode 5: During braking or deceleration (fig 5e) both the front and rear wheel EMs acts as generators to simultaneously charge the battery.
- Mode 6: A unique operating mode of complex hybrid system is axial balancing. In this mode (fig 5f) if the front wheel slips, the front EM works as a generator to absorb the change of ICE power. Through the battery, this power difference is then used to drive the rear wheels to achieve the axle balancing.

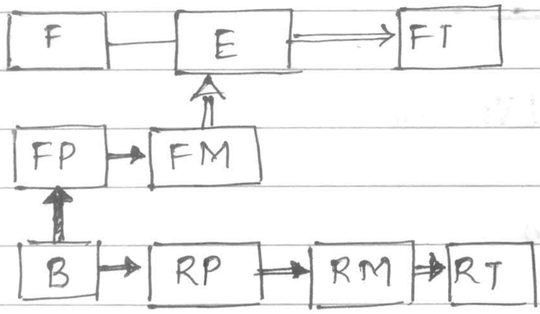

fig 5a Mode 1 Start up

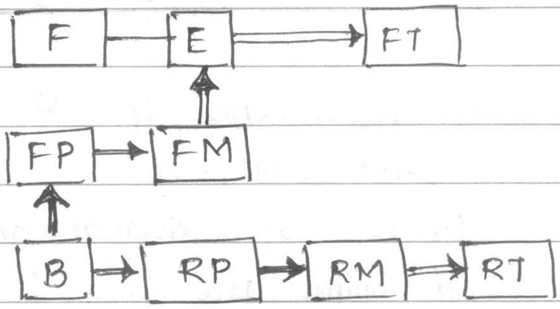

fig 5b Mode 2, full throttle acceleration

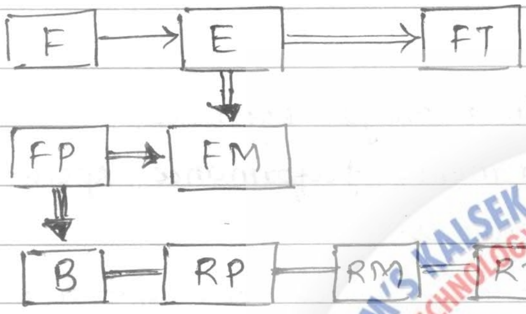

fig 5c Mode 3, vehicle propel & Battery charging

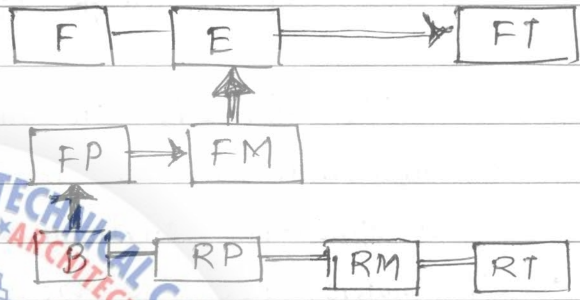

fig 5d Mode 4, light load

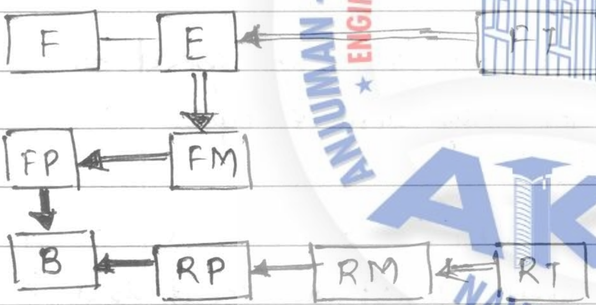

fig 5e Mode 5, Breaking or deceleration

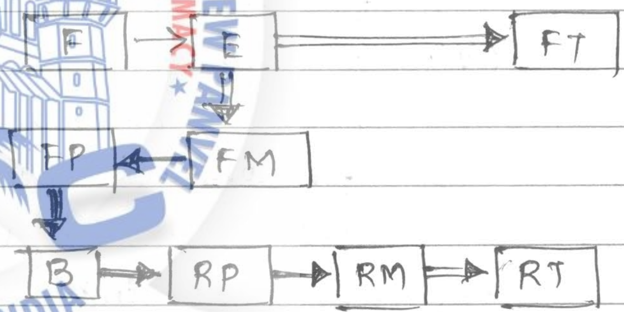

fig 5f Mode 6 axial balancing

B: Battery FM: front motor FP: front power converter
FT: front axel transmission E: ICE F: fuel tank
RM: Rear motor RP: Rear power conveter
RT: Rear axle transmission
—— Electrical link
—— Hydraulic link
═══ Mechanical link.

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Considerations of EM's used in EV's

The requirements of EM's used in EV's are:

- Frequent start / stop
- High rate of acceleration and deceleration
- High torque low speed hill climbing
- Low torque cruising.
- Very wide speed range of operation.

The EMs for EVs are unique and their major differences with respect to industrial motors in load requirement, performance specification and operating environment are as follows.

- EV motors need to produce the maximum torque that is four to five times of the rated torque for acceleration and hill climbing, while the industrial motors generally offer the maximum torque that is twice of the rated torque for overload operation.
- EV motors need to achieve four to five times the base speed for highway cruising, while industrial motors generally achieve up to twice the base speed for constant power operation.
- EV motors require high power density as well as good efficiency map (high efficiency over wide ~~spread~~ speed and torque ranges), while industrial motors are generally optimized to give high efficiency at a rated point.
- EV motors need to be installed in mobile vehicles with ~~difficult~~ unpleasent operating conditions such as high temperature, bad weather and frequent vibrations, while industrial motors are generally located in fixed places.

Electric Vehicle (EV) Configuration Based on Power transmission Mode.

There are many possible EV configurations due to the variations in electric propulsion and enegy sources. Based on these variations, 6 alternatives are possible as shown in figure.

[Configuration 1]

fig 1 (a)

In fig 1 (a) a single electric motor configuration with gear box (GB) a clutch and a differential (D)

- The clutch (C) enables the connection or disconnection of power flow from EM to the wheels.
- The gear consists of a set of gears with different gear ratio [A gear ratio is a direct measure of the ratio of rotational speeds of 2 or more interlocking gears]
- The wheels have high torque low speed in lower gears and high speed low torque in the higher gears.

[Configuration 2]

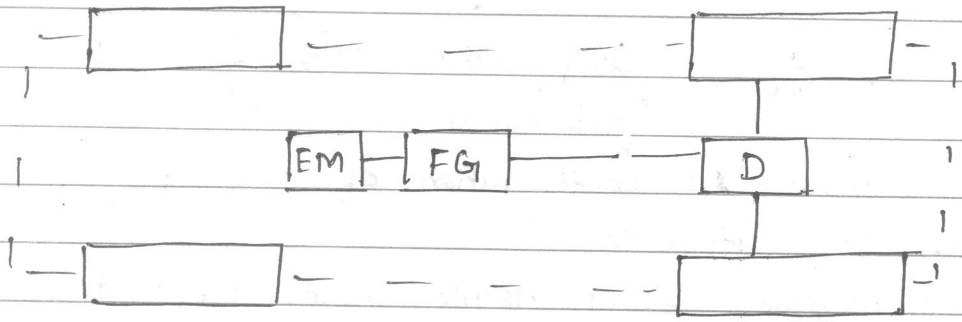

fig 1 (b) Configuration without gear box & clutch.

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- In fig 1 (b) a single EM configuration without the gear box and clutch is shown.
- It uses fixed gears which is similar to autogear vehicles.
- The advantage of this configuration is that the weight of the transmission is reduced ie. the weight of assembly is reduced considerably.
- However this configuration demands a more complex control of the EM to provide the necessary torque to the wheels. The control system needed for auto gear feature is also complex.
- A differential is a standard component for conventional vehicles. When a vehicle is rounding a curved road, the outer wheels need to travel on larger radius than the inner wheel. Thus, the differential adjusts the relative speeds of the wheels. If relative speeds of the wheels are not adjusted then the wheels will slip and result in tire wear, steering difficulties and poor road holding.

[Configuration 3]

fig 1(c) Configuration with fixed gears & differential.

- The fig 1(c) shows a configuration of EV using 1 Electric motor fixed gears and differential.
- It is a transverse front electric motor wheel drive configuration.
- The fixed and differential are integrated into a single assembly.

Front Wheel Drive Configuration

- It is a form of engine and transmission layout used in motors vehicles, where the engine drives the front wheels only.
- Modern front wheel drive features a transverse engine.

Transverse Engine : It is an engine mounted in a vehicle so that the engine's (crankshaft) perpendicular to the long axis of the vehicle.

Configuration 4 :

fig 1 (d)

The fig 1 (d) shows dual motor configuration is shown.

- In this configuration the differential action of an EV when concerning can be electronically provided by two electric motors.
- The motion of the electric motor is transfered to the wheels through fixed gears.

Configuration 5:

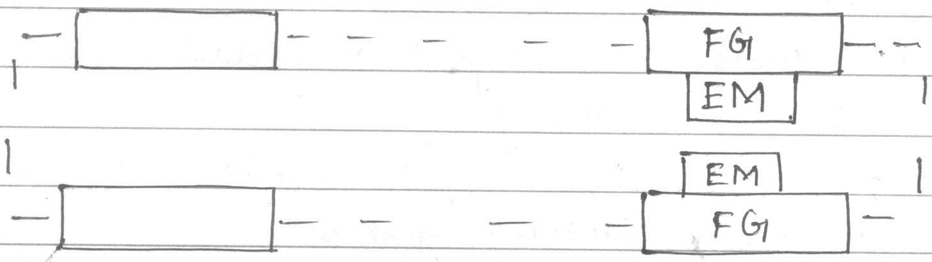

fig 1 (e)

- In order to shorten the mechanical transmission path from the electric motor (EM) to the driving wheel, the EM can be placed inside a wheel.

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- This configuration in which fixed planetary gearing is employed to reduce the motor speed to the desired wheel speed. fixed planetary gearing : Planetary gearing is a gear system consisting of one or more outer gears.

Configuration 6 :

fig 1(f)

- In fig 1(f) an EV configuration without any mechanical gearing is shown. By full abandoning (seperate) any mechanical gearing.
- In wheel drive can be realized by installing a low speed outer rotor electric motor inside a wheel.

* High speed inner rotors:

- These are the motors which are used when a fixed speed reduction gear becomes necessary to attain a reliastic wheel speed.
- In general, Speed reduction is achieved using a planetary gear set. This planetary gear is mounted between the motor shaft and the wheel rim.
- Usually this motor is designed to operate upto 1000 rpm so as to given high power density.
They are of smaller size, lighter weight and lower cost
- and needs additional planetary gear set.

* Outer rotor motors:

- These are motors used when the transmission can be totally removed and the outer rotor acts as the wheel rim and motor speed is equivalent to the wheel speed and no gears are required.
- They are of low speed and hence does not require additional gears
- The drawbacks are larger size, weight and cost because of low speed design.

Electric Vehicle Configuration Based on Source of Power Used.

Besides the variation in electric propulsion, there are other EV configurations due to variations in energy sources. There are 5 possible configurations.

Configuration 1

fig 1 (a) B- Battery P- Power convertor

- It is a simple battery configuration fig 1 (a)
- The battery may be distributed around the vehicle packed together at the vehicle back or located beneath the vehicle chassis (base frame of car)
- The battery in this case should have reasonable specific energy and specific power and should be able to accept regenerative energy during braking.

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[In case of EV's the battery should have both high specific energy and specific power because high specific power governs the driving range while the high power density governs the acceleration and hill climbing capability.

Configuration 2

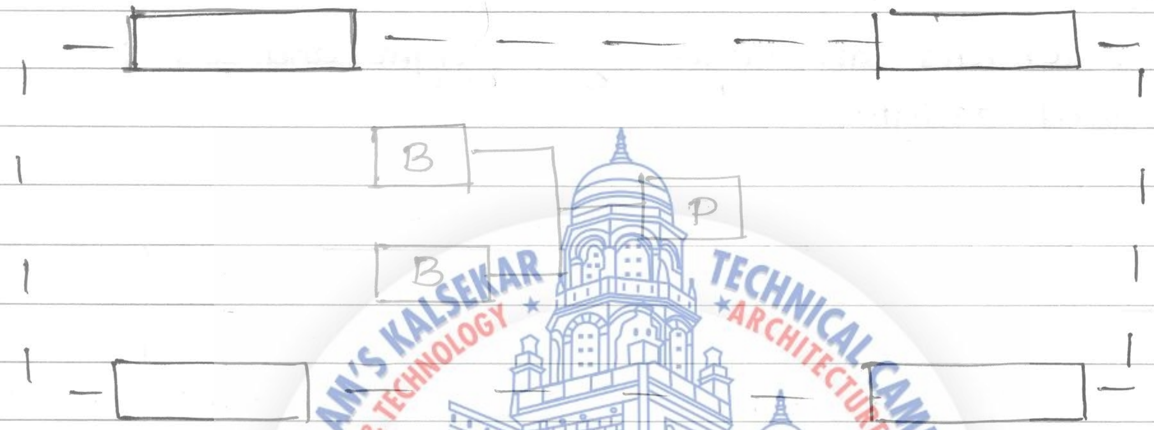

fig 1 (b)

In this configuration instead of 2 same batteries this design uses 2 different batteries. One battery is optimized for high specific energy and another battery for high specific power.

Configuration 3

In this arrangement fuel cell is used. The battery is an energy storage device, whereas the fuel cell is an energy generation device.

The operation principle of fuel cells is a reverse process of electrolysis. In reverse and electrolysis, hydrogen and oxygen gases continue to form electricity and water.

The hydrogen gas used by the fuel cell can be stored in an on-board tank. where as oxygen gas is extracted from air.

Since fuel cell can offer high specific energy but cannot accept regenerative energy, it is preferable to combine it with battery with high specific power and high specific energy respectively.

Configuration 4

fig 1(d).

Rather than storing it is as a compressed gas, a liquid or a metal hydride can be generated on board using liquid fuels such as methanol.

In fig 1 (d) In this a case of a mini reformer is installed in the EV to produce necessary hydrogen gas for the fuel cell.

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Configuration 5

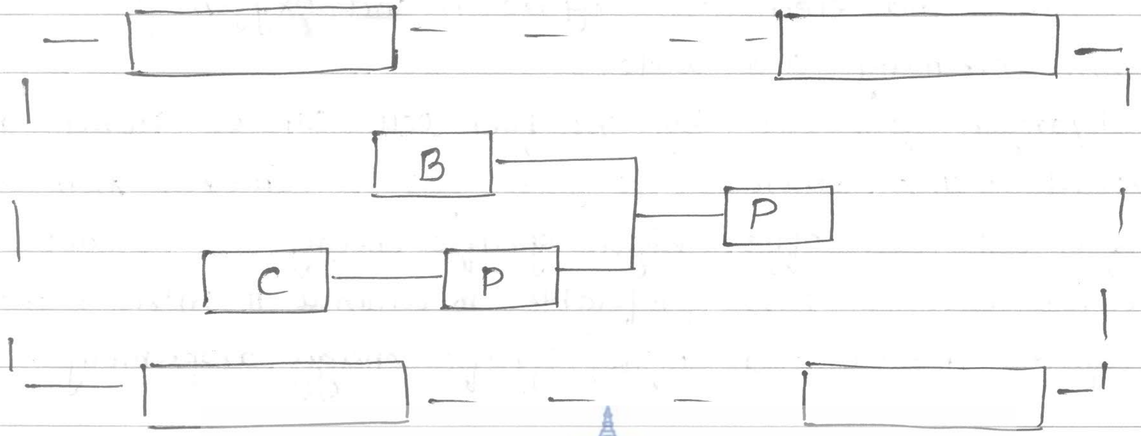

fig 1 (e)

- In fuel cell and battery combination, the battery is selected to provide high specific power and high energy respectively.
- In this configuration a battery and supercapacitors combination is used as an energy source
- In fig 1 (e) The battery used in this configuration is a high energy density device where as the super capacitors are of relatively low voltage levels, an additional dc-dc power convertor is needed to interface between the battery and capacitor terminals.