DESIGNING CONTROL STRATEGIES FOR HYBRID ELECTRIC VEHICLE

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HYBRID ELECTRIC VEHICLE AND ELECTRIC MOTOR DRIVE

Outline

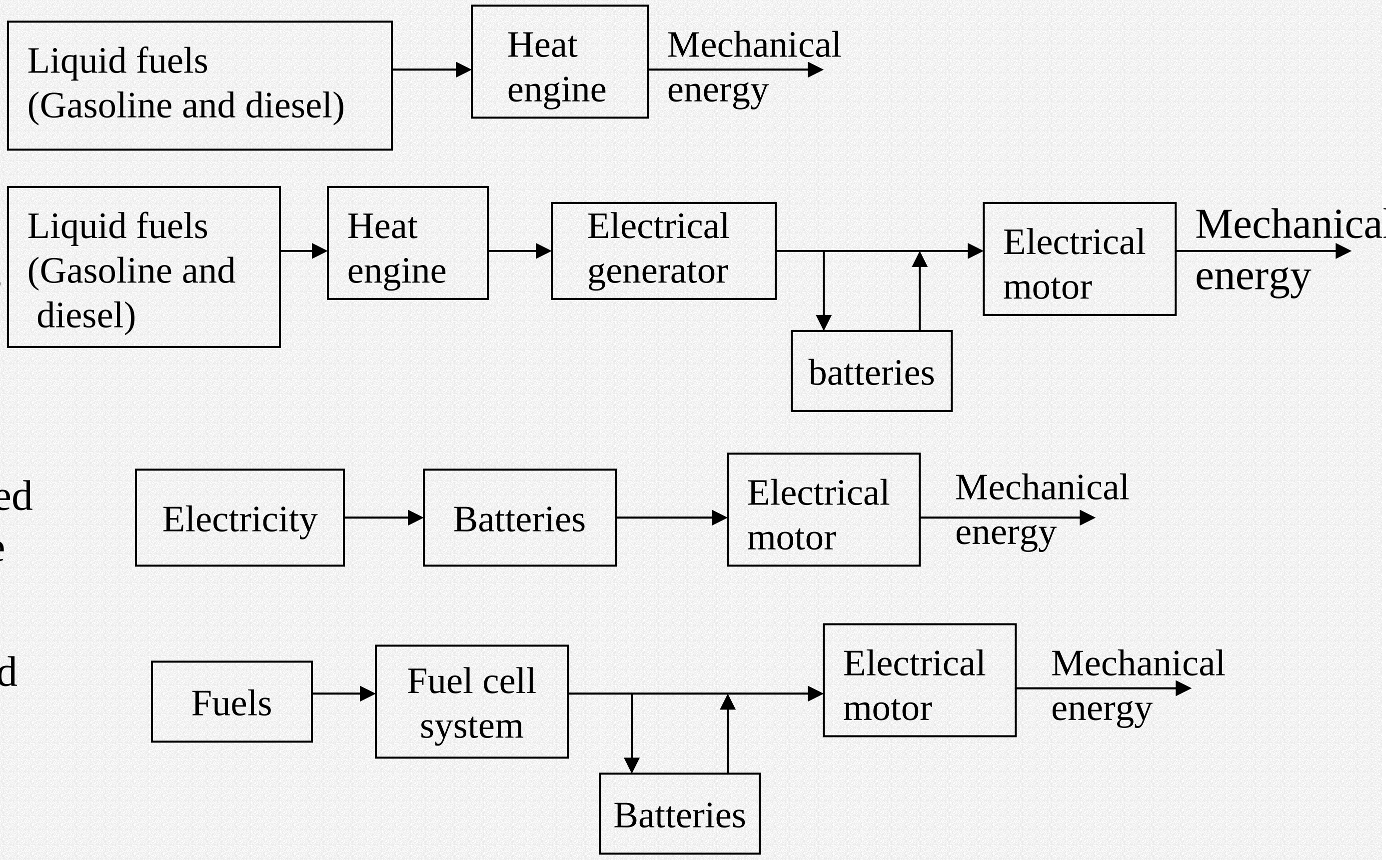
- Basic performance requirements of land vehicles
- Energy and energy conversion system current available for transportation
- Brief review of the traction system and performance of conventional vehicle
- Battery powered electric vehicle drive train
- Hybrid vehicle drive train
- Regenerative braking of EV and HEV
- Control strategies for HEV drive train
- Electric energy storage
- Basic requirements of traction motor for EV and HEV
- Commonly used motor drive
- Control of IM drive for traction

BASIC PERFORMANCE REQUIREMENTS OF LAND VEHICLES

- Requirements of users
  - •Good performance: such as, high speed, high acceleration
  - •Good Reliability
  - •Driving convenience:such as, ready to go, sufficient driving range, etc.
  - •Safety: such as: good braking and handling performance
  - •Cost: low initial and utilization cost
- Environment issues
  - •Less pollutant emissions
- Energy source issues
  - •Good match to energy supplies
  - •Less energy consumption
- Match traffic conduction
  - •Road condition: such as, friction between tire and road surface, grade, curve….
  - •Hard obstacle negotiation and soft ground mobility
  - •Traffic management, signals for example,
- Manufacturing

ENERGY AND ENERGY CONVERSION SYSTEMS CURRENTLY AVAILABLE FOR TRANSPORTATION

- Conventional vehicles
- ICE-based hybrid vehicles
- Battery powered electric vehicle
- Fuel cell-based hybrid vehicle



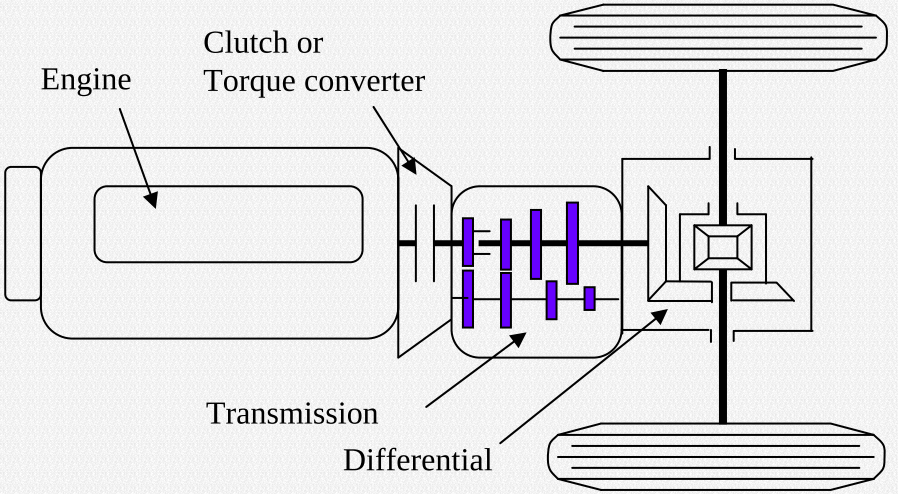
BRIEF REVIEW OF THE TRACTION SYSTEM AND PERFORMANCE OF CONVENTIONAL VEHICLES

•Engine: the power producer

•Clutch (manual transmission) or torque converter (automatic transmission): coupling or decoupling the engine power to the driven wheels.

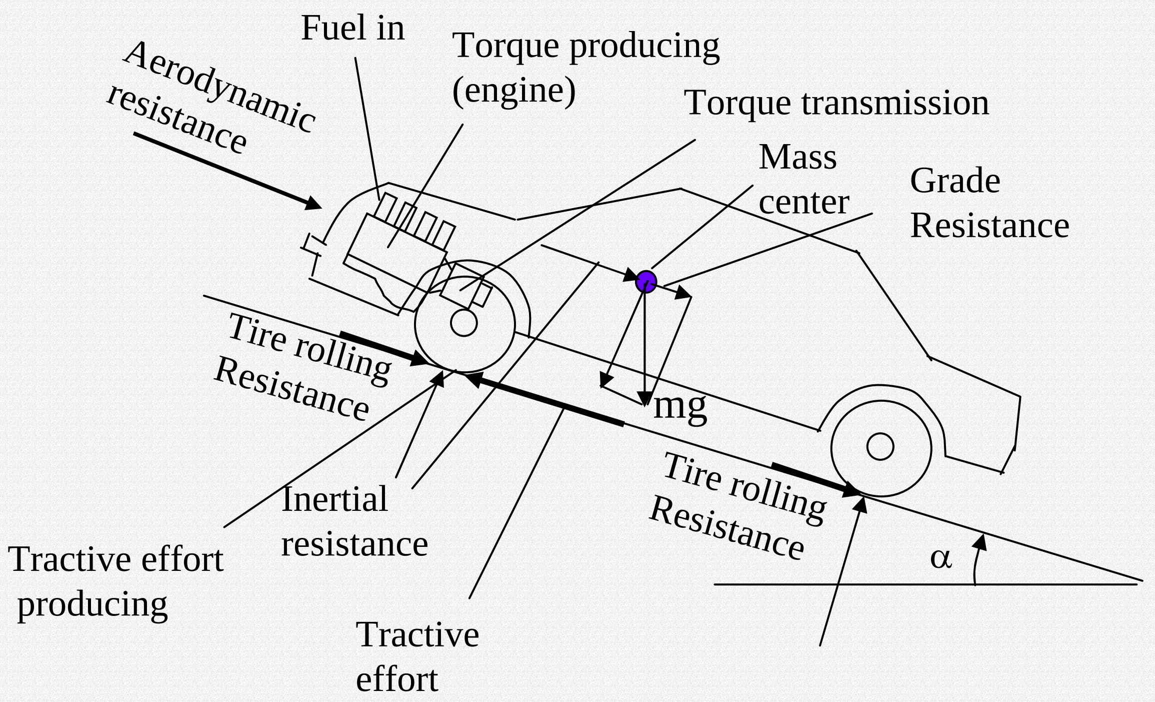
•Transmission (gear box): modifying the torque-speed profile of the engine in order to meet the requirement of torque-speed profile on the driven wheels

•differential: allowing two driven wheels to have different angular velocity, which is necessary while vehicle driving along a curve path



BRIEF REVIEW OF THE TRACTION SYSTEM AND PERFORMANCE OF CONVENTIONAL VEHICLES

•Forces acting on a vehicle (for traction analysis)



BRIEF REVIEW OF THE TRACTION SYSTEM AND PERFORMANCE OF CONVENTIONAL VEHICLES

- **Vehicle Resistance**
  - Tire (track) rolling resistance: $F_r = M.g.f.\cos(\alpha)$

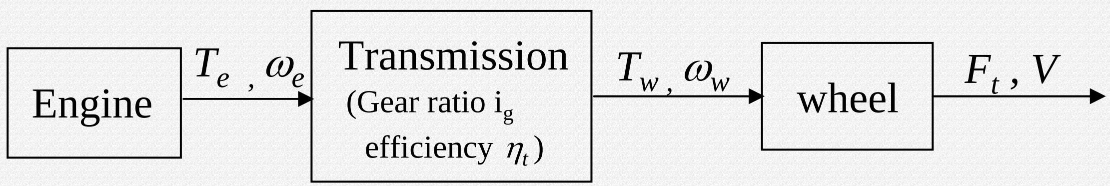
    M=vehicle mass, g=9.81m/s^2 , f= rolling resistance coefficient and, α=road slope angle
  - Aerodynamic drag: $F_w = \frac{1}{2}\rho_a C_D A_f V^2$

    ρ_a=air mass density, *1.205 kg/m^3* , C_D=aerodynamic drag coefficient,
    A_f---front area of the vehicle in m^2, V ---vehicle speed, m/s
  - Grade Resistance: $F_i = M.g.\sin\alpha$
  - Inertial resistance in acceleration: $F_j = \delta M \frac{dV}{dt}$

    dV/dt = vehicle acceleration in m/s^2, δ = mass factor due to rotating components
  - Total vehicle resistance: $F_{res} = F_r + F_w + F_i + F_j$

BRIEF REVIEW OF THE TRACTION SYSTEM AND PERFORMANCE OF CONVENTIONAL VEHICLES

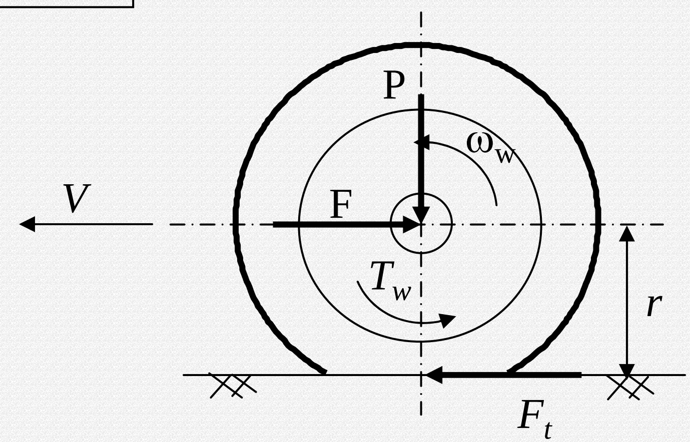
- Tractive effort
  - The tractive effort is the force action on the driven wheels, which thrusts the vehicle forward.
  - The tractive effort comes from the engine torque, modified by the transmission.



$$F_t = \frac{T_w}{r} = \frac{T_e \cdot i_g \cdot \eta_t}{r}$$

And

$$V = \omega_w \cdot r = \frac{\omega_e \cdot r}{i_g} = \frac{n_e \cdot r \cdot \pi}{30 \cdot i_g}$$



Where, T_e-engine torque, *N.m*, ω_e – engine angular velocity, *rad/s*

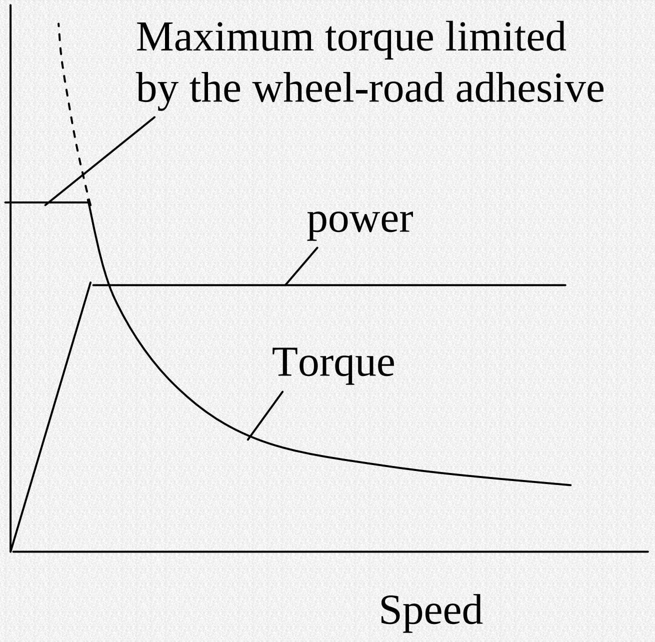
n_e – *engine rpm*

BRIEF REVIEW OF THE TRACTION SYSTEM AND PERFORMANCE OF CONVENTIONAL VEHICLES

- ‘Ideal” torque (power) – speed characteristics for traction

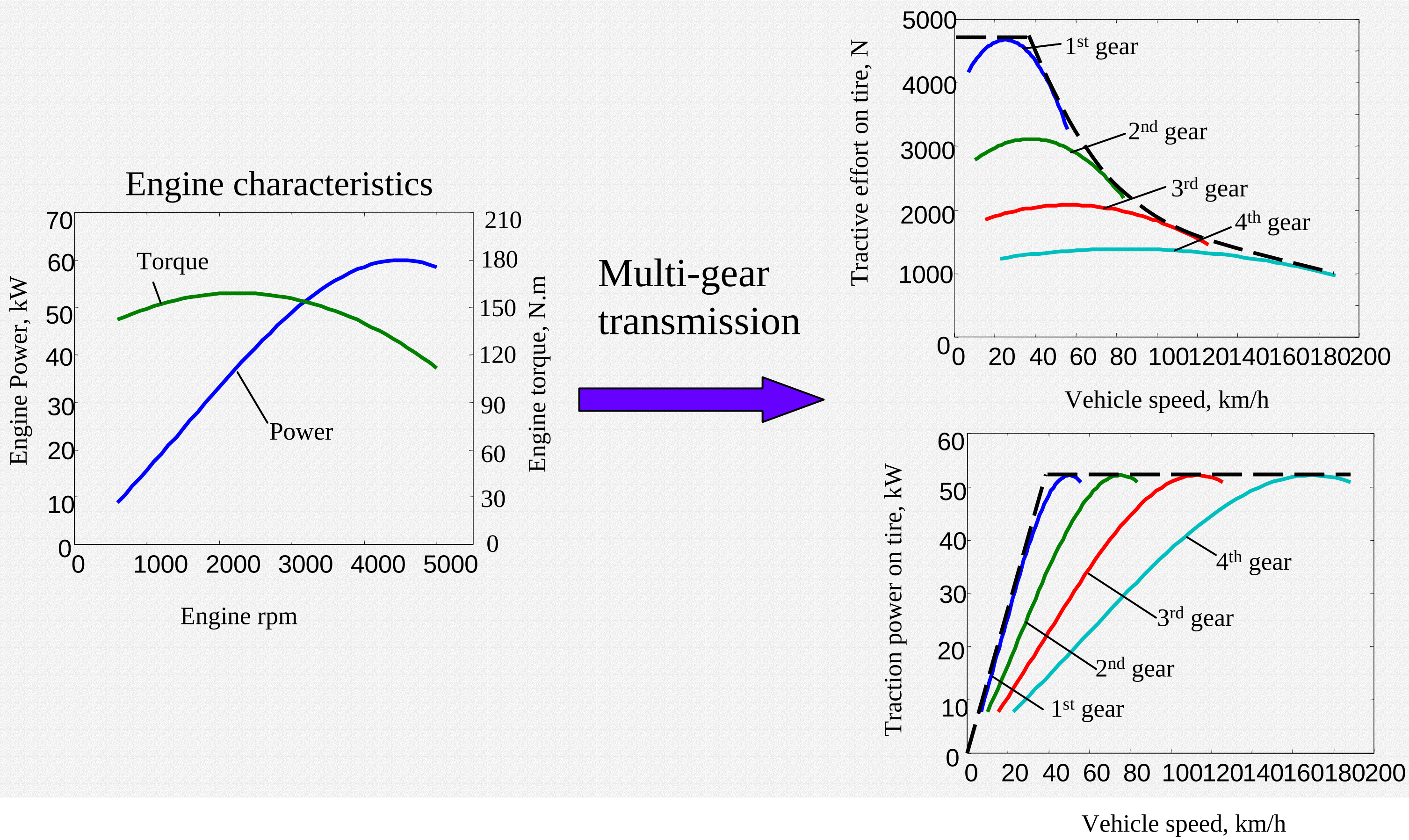
  - “Ideal” torque (power)-speed characteristics for traction is the constant power profiles, but at low speed, constant torque, which is limited by the wheel-road adhesive ability (maximum friction force)

  - Constant power characteristics can results in the best acceleration and gradeability performance with a given rated power.



BRIEF REVIEW OF THE TRACTION SYSTEM AND PERFORMANCE OF CONVENTIONAL VEHICLES

•Multi-gear or Continuous Variable Transmission Is Required For IC Engine Power Vehicle



BRIEF REVIEW OF THE TRACTION SYSTEM AND PERFORMANCE OF CONVENTIONAL VEHICLES

- Fuel economy characteristics of IC engine vehicle
  - Fuel consumption of a IC engine vehicle can be calculated by

$$Q_s = \int_0^t \frac{P_e \cdot g_e}{3.6 \times 10^6 \gamma_f} dt \quad \text{(Liters)}$$

Where, P_e --- engine traction power in kW

g_e--- engine specific fuel consumption in grams/kW.h

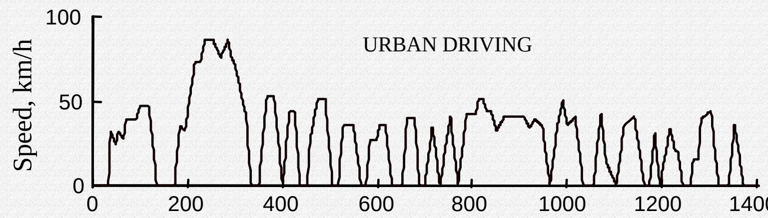
γ_f--- fuel mass density, kg/liter

t--- time in Sec.

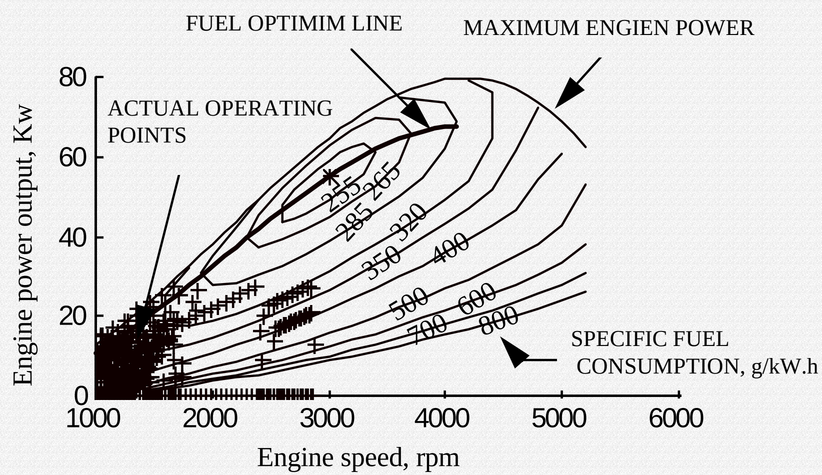
BRIEF REVIEW OF THE TRACTION SYSTEM AND PERFORMANCE OF CONVENTIONAL VEHICLES

- **Engine has a poor average fuel utilization efficiency**

1500 kg passenger car



EPA75 urban driving

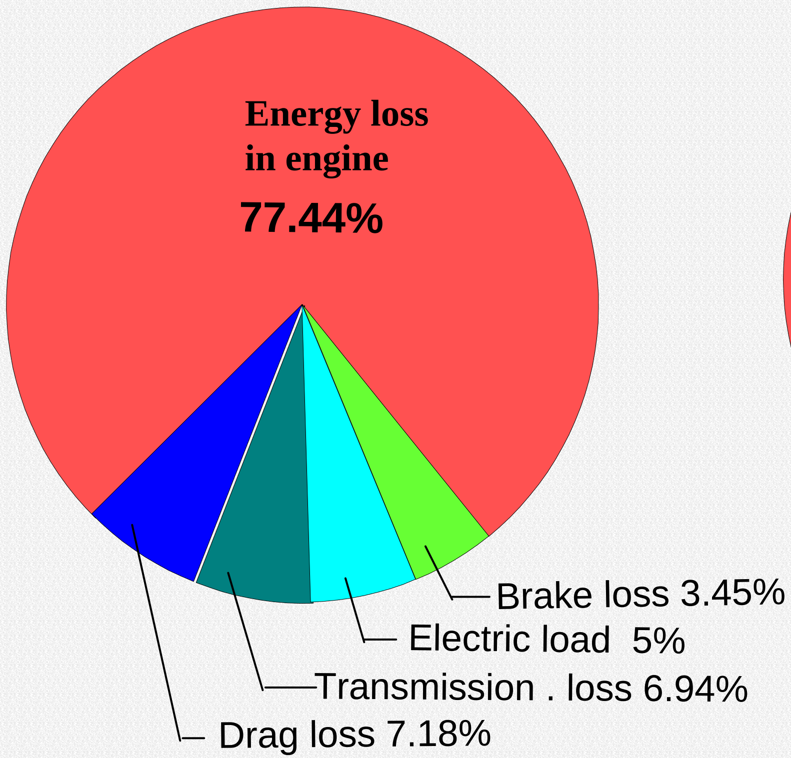


Fuel economy: 12.8 L/100km (18.5 mpg)

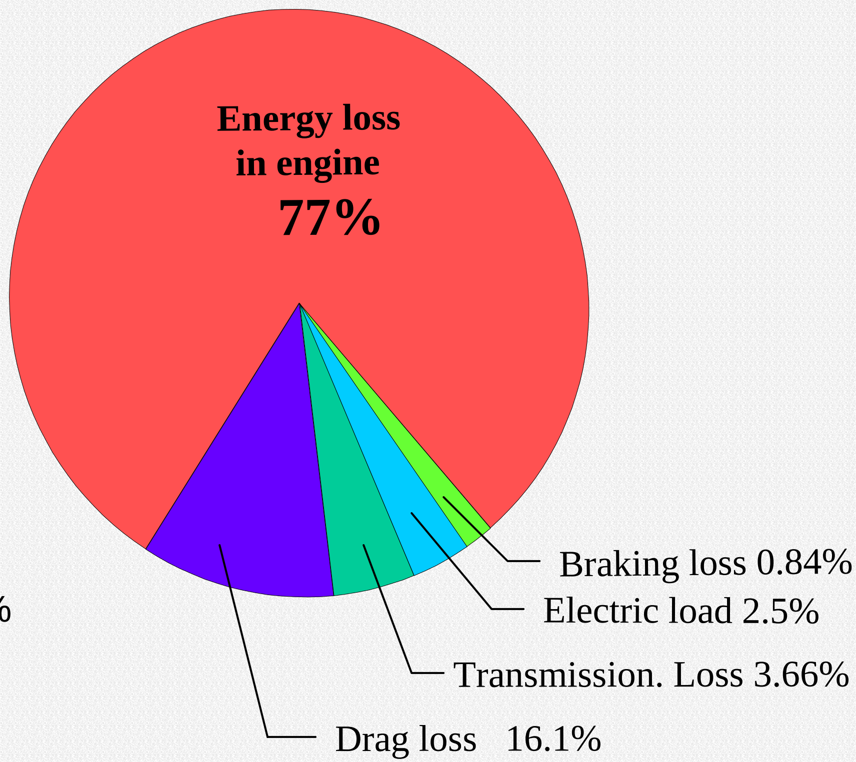
BRIEF REVIEW OF THE TRACTION SYSTEM AND PERFORMANCE OF CONVENTIONAL VEHICLES

•**Energy loss in individual component**

FTP 75 urban Driving cycle



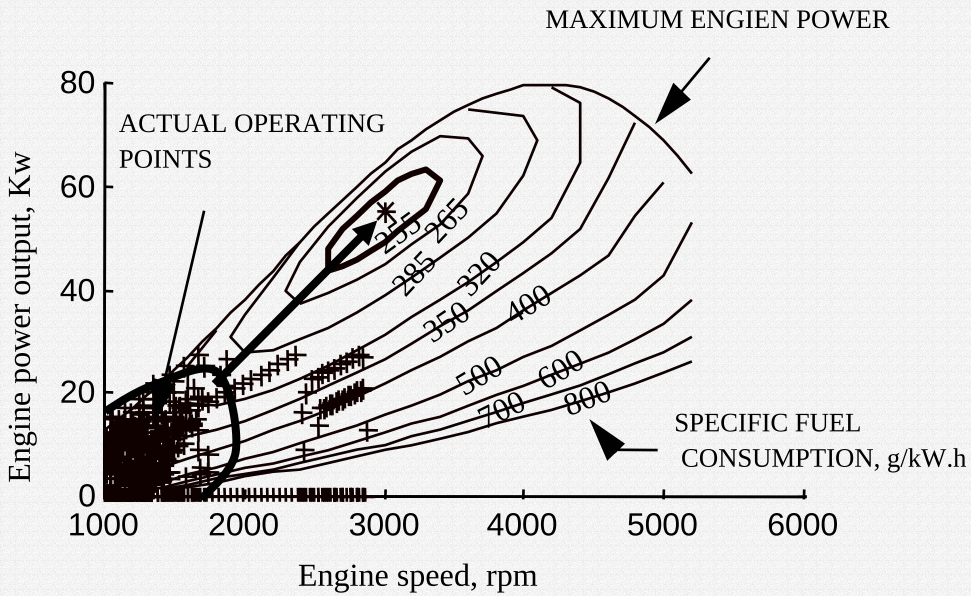
FTP 75 highway driving cycle



BRIEF REVIEW OF THE TRACTION SYSTEM AND PERFORMANCE OF CONVENTIONAL VEHICLES

•Basic techniques to improve fuel economy of ICE Vehicle (cont.)

- •Advanced drive trains
  Hybrid drive train is a good practice in development of advanced drive trains the strategy used in HEV is to move the operating points to the optimal operation region (down size the engine)
- •Eliminate the inefficient fluid-coupling torque converter
- •Effective regenerative braking



BATTERY POWERED ELECTRIC VEHICLE DRIVE TRAIN

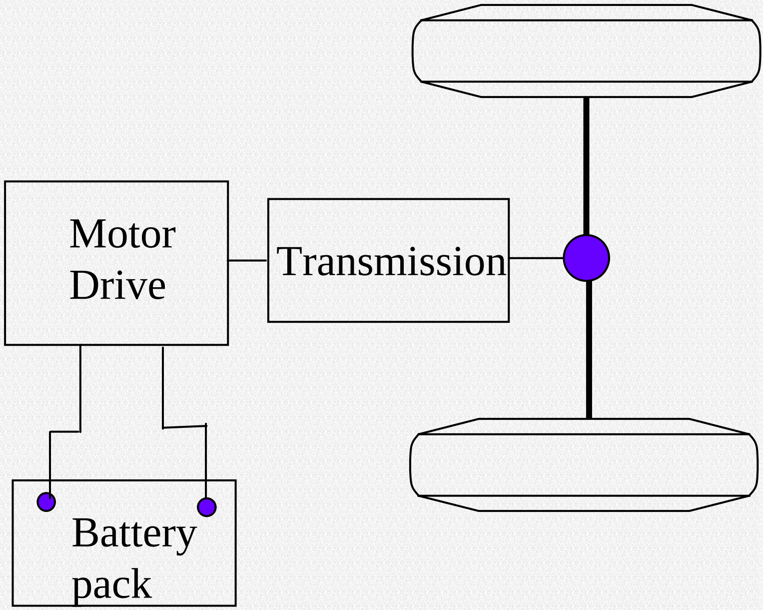
•Configuration of Battery Powered Electric Vehicle

- Battery power EV has a very simple structure
- However, battery is the biggest problem

- Advanced motor drive can significantly improve the EV performance (discuss later)

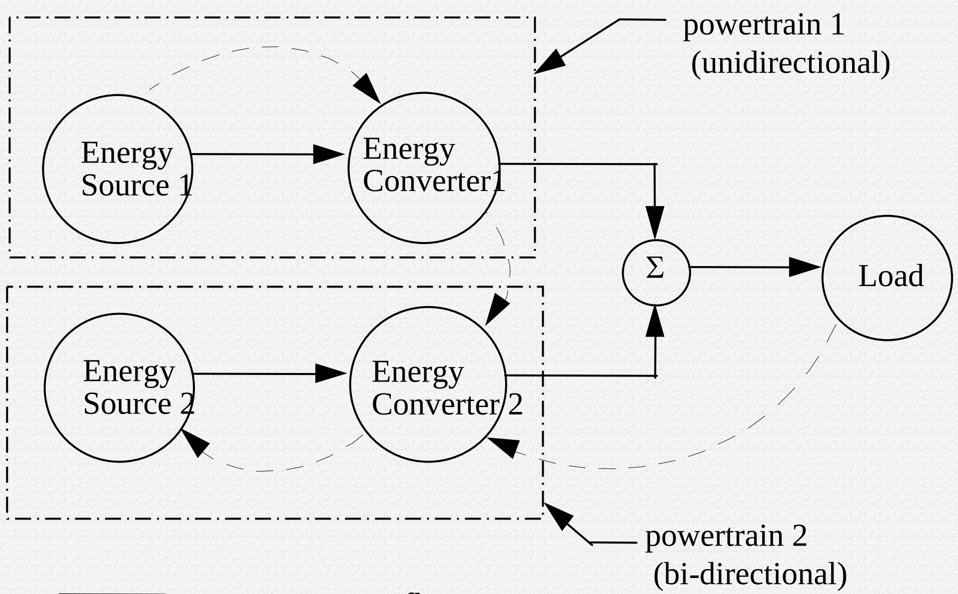
- Hybridized energy storage (battery-ultracapacitor) can further improve the EV performance greatly (discuss later)

- Optimally designed EV can meet some specific utilization



HYBRID VEHICLE DRIVE TRAIN

•Basic concept of hybrid drive train



Tractive power flows

Power flows into bi-directional energy converter and energy source

For powertrain 1:

$$P_{P1} \begin{cases} > 0 \text{ (traction)} \\ = 0 \text{ (idling or shut down)} \end{cases}$$

For powertrain 2:

$$P_{P2} \begin{cases} > 0 \text{ (traction)} \\ = 0 \text{ (idling or shut down)} \\ < 0 \text{ energy recovery} \end{cases}$$

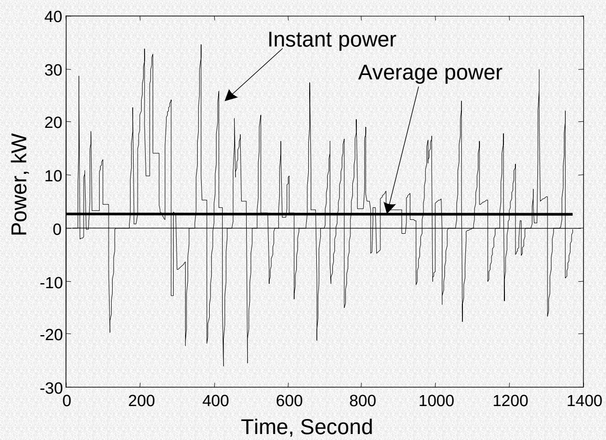
For load:

$$P_{L} \begin{cases} > 0 \text{ (traction)} \\ = 0 \text{ (standstill or coasting)} \\ <0 \text{ (braking)} \end{cases}$$

Constraint: $P_{P1} + P_{P2} = P_L$

HYBRID VEHICLE DRIVE TRAIN

- Vehicle load can be divided into two components--- Static (average) and dynamic load (zero average)
- Hybrid drive train has two power plants--- static and dynamic
- IC engine or fuel cell serves as static power plant
- Battery/ultracapacitor-electric motor serves as dynamic power plant



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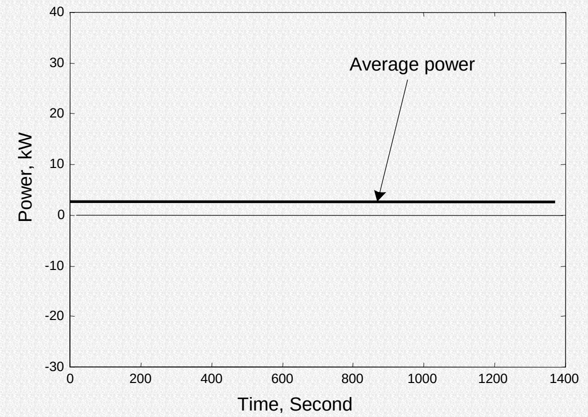

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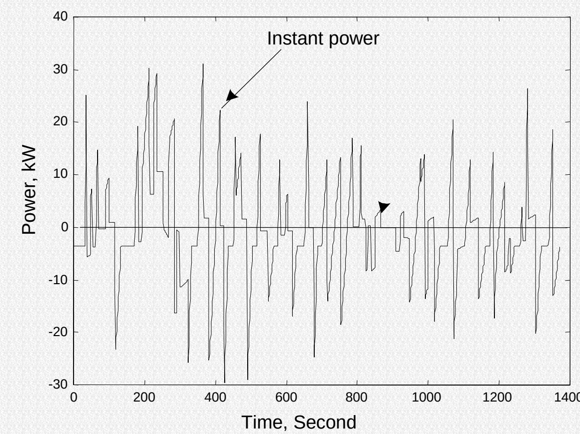
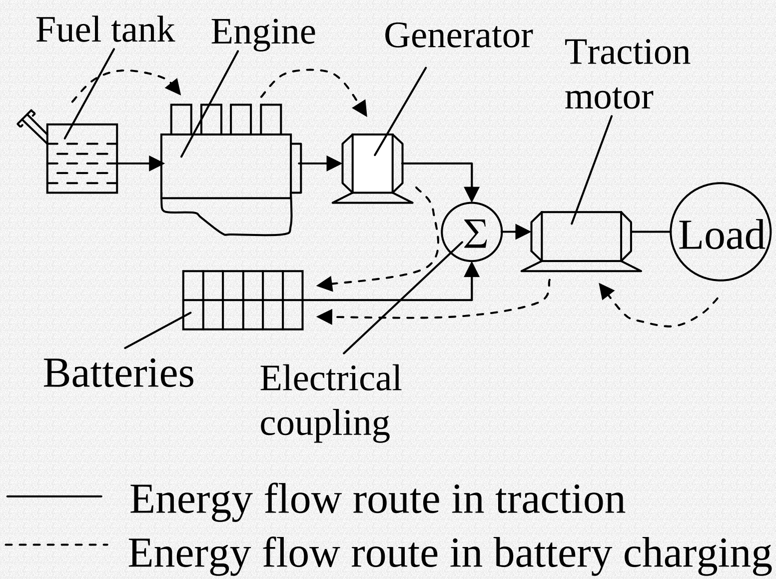


HYBRID VEHICLE DRIVE TRAIN

•Series Hybrid Electric Vehicle



Available operation modes:

•Engine alone traction mode:
Fuel-→Engine-→Generator-→Traction motor-→Load

•Battery alone traction mode :
Battery -→ traction Motor -→ load

•Hybrid traction mode:
Fuel -→Engine-→generator-→traction Motor-→Load
and, battery -→traction Motor -→ Load

•Regenerative braking mode:
load-→ Traction Motor -→ Battery

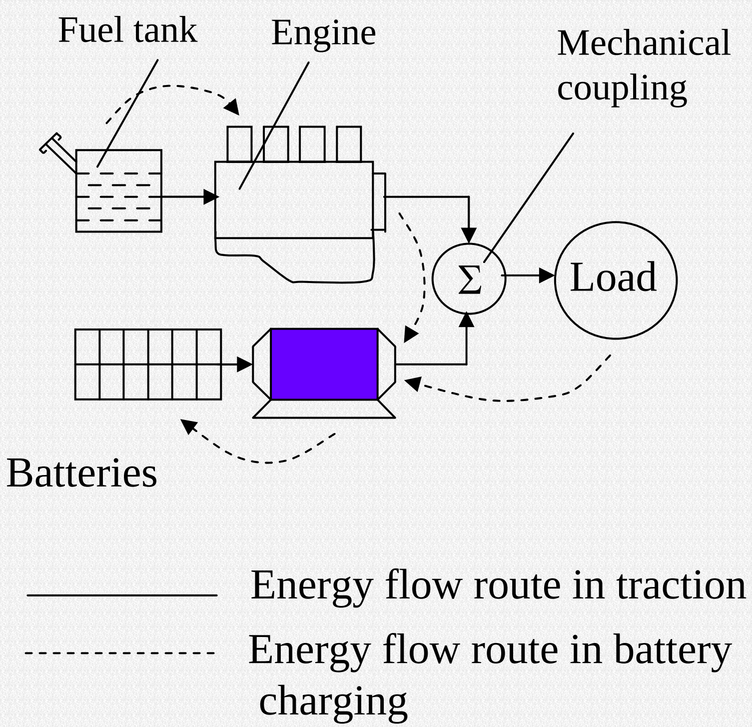
•Battery charging from engine
Fuel-→Engine-→Generator-→Battery.

•Engine power split mode:
Fuel -→Engine-→Generator-→ Load
Generator-→ Battery.

•Both engine and load charging batteries
Fuel -→Engine-→Generator-→Battery.
Load -→Traction Motor -→ Battery.

HYBRID VEHICLE DRIVE TRAIN

•**Parallel Hybrid Electric Vehicle**



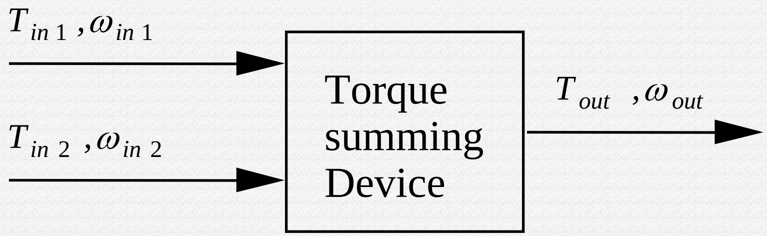
Available operation modes:

•Engine alone traction mode:
Fuel -⟶Engine. -⟶ Load
•Battery alone traction mode :
Battery -⟶ Traction Motor -⟶ Load
•Hybrid traction mode:
Fuel -⟶ Engine-⟶ Load
Battery -⟶Traction Motor -⟶ Load
•Regenerative braking mode:
Load-⟶ Traction Motor -⟶ Battery
•Battery charging from engine
Fuel -⟶ Engine -⟶ Traction motor-⟶Battery
•Engine power split mode:
Fuel -⟶Engine -⟶ Load
Eng-⟶ Traction Motor -⟶ Battery.
•Both engine and load charging batteries
Fuel -⟶ Engine-⟶ Traction Motor -⟶ Battery
Load -⟶ Traction Motor -⟶ Battery

HYBRID VEHICLE DRIVE TRAIN

•Parallel Hybrid Drive Train With Torque Summing

•A torque summing device adds tow powers together by summing two torques together which are independent from each other and two speeds are dependent on each other.



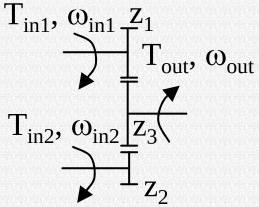
$$T_{out} = k_1 T_{in1} + k_2 T_{in2} \quad \text{And} \quad \omega_{out} = \frac{\omega_{in1}}{k_1} = \frac{\omega_{in2}}{k_2}$$

Where, k_1 and k_2 are constants, which depend on the design of the torque summing device

HYBRID VEHICLE DRIVE TRAIN

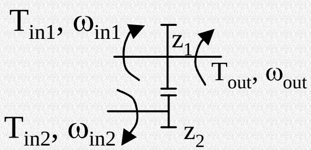
•Some examples of torque summing devices for parallel HEV

Gear Box



$$k_1 = \frac{z_3}{z_1} \quad k_2 = \frac{z_3}{z_2}$$

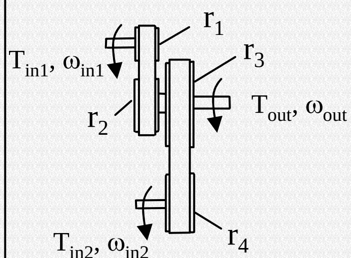
z_1 z_2 and z_3
---tooth number
of gears



$$k_1 = 1 \quad k_2 = \frac{z_1}{z_2}$$

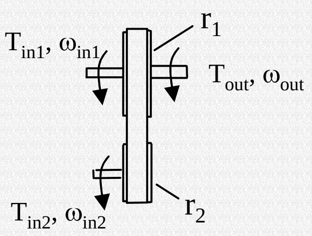
z_1 and z_2
---tooth number
of gears

Pulley or chain assembly



$$k_1 = \frac{r_2}{r_1} \quad k_2 = \frac{r_3}{r_4}$$

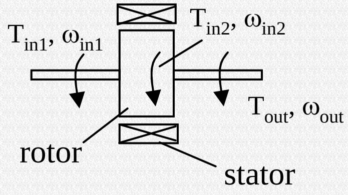
r_1, r_2,r_3 and $r_{4,}$ the
Radius of pulleys



$$k_1 = 1 \quad k_2 = \frac{r_1}{r_2}$$

$R_1$and $r_{2,}$ the
Radius of pulleys

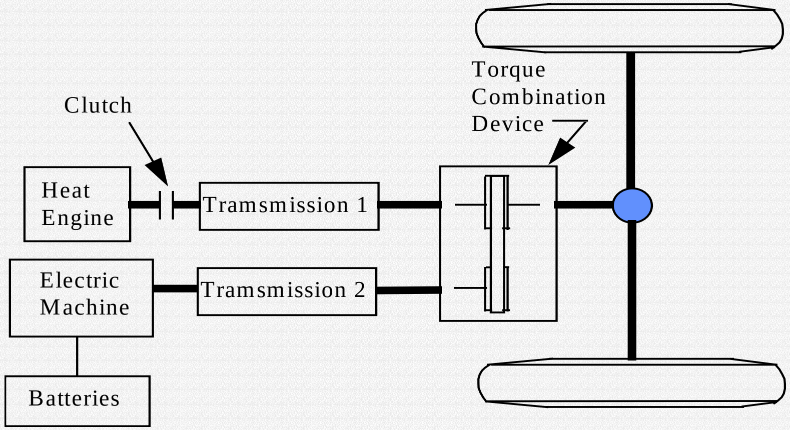
shaft



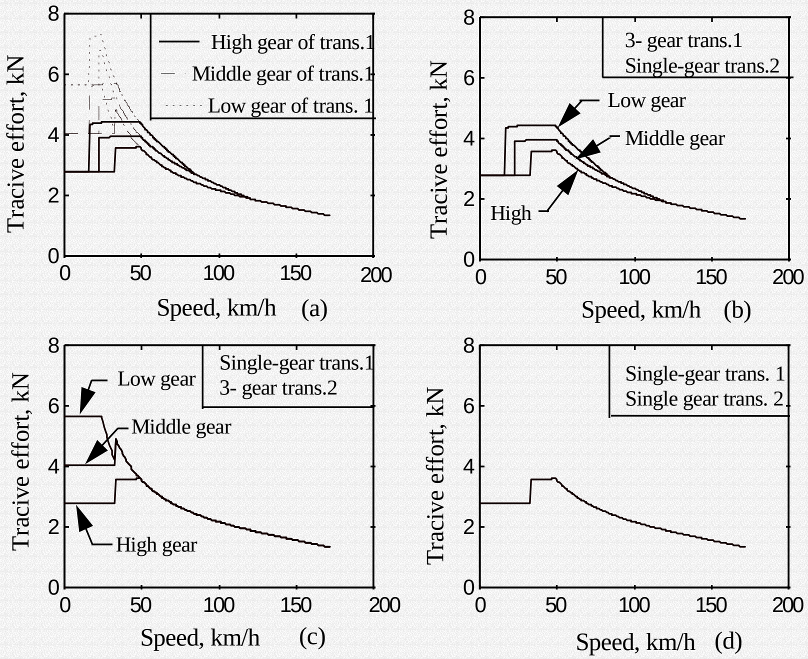
k_1=1,
k_2=1

HYBRID VEHICLE DRIVE TRAIN

- Parallel hybrid drive with torque summing and two axles



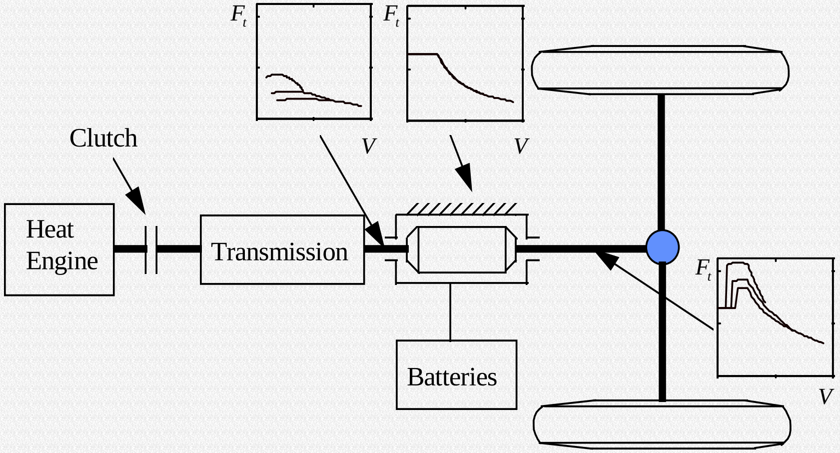
Tractive effort profiles for various transmission arrangement



(a) Both trans. have 3-gears
(b) Trans. 1 has 3-gears, and Trans.2 has 1-gear
(c) Trans.1 has 1-gear and trans.2 has 3 gears
(d) Both trans. have 1 gear

HYBRID VEHICLE DRIVE TRAIN

•**Parallel hybrid drive with torque summing (single axle and one transmission)**



Features:

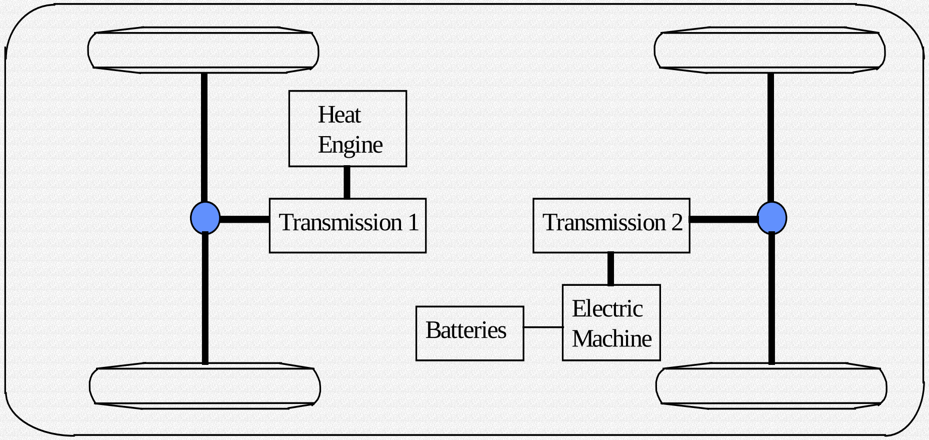
•Compact design

•Multi-gear transmission can adjust the operation of the engine

•This design may be a proper design in which a small engine and large motor are used

HYBRID VEHICLE DRIVE TRAIN

•**Parallel hybrid drive with torque summing (Separated-Axle drive)**



Features:

•The vehicle body acts as the torque combination device

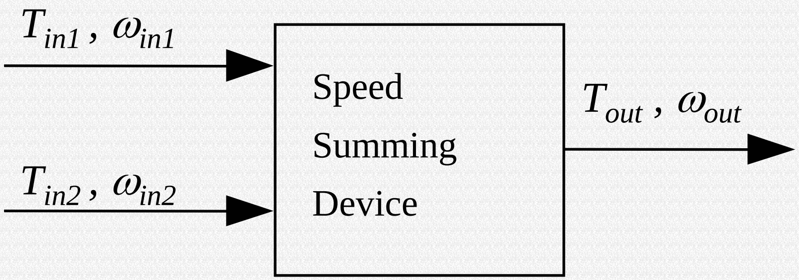
•Four-wheel driving

•Electric traction system are independent from IC engine traction system

•When Trans. 2 is single-gear, two motors may be used and put into wheels thus leading to a very simple construction

HYBRID VEHICLE DRIVE TRAIN

- **Parallel Hybrid Drive Train with Speed Summing**
  - A speed summing device adds tow powers together by summing two speed together which are independent from each other and two torques are dependent on each other



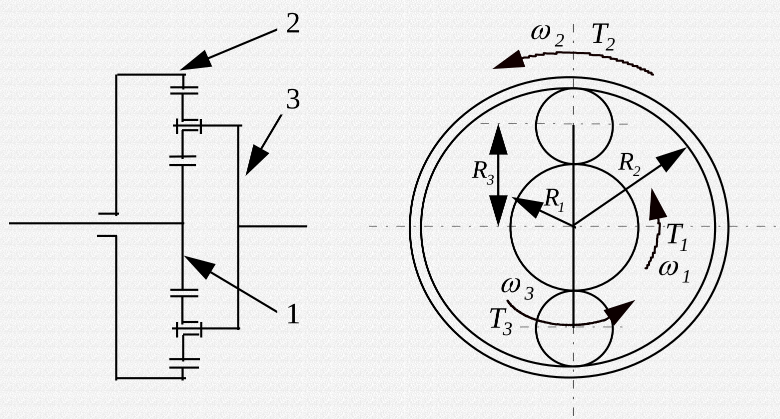
$$T_{out} = k_1 T_{in1} = k_2 T_{in2} \quad \text{and} \quad \omega_{out} = \frac{\omega_{in1}}{k_1} + \frac{\omega_{in2}}{k_2}$$

k_1 and k_2 are constants

HYBRID VEHICLE DRIVE TRAIN

•**Examples of speed summing devices**

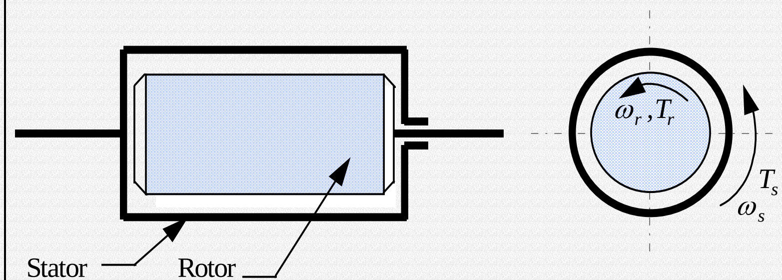
Planetary gear unit



$$T_3 = \frac{2R_3}{R_1} T_1 = \frac{2R_3}{R_2} T_2$$

$$\omega_3 = \frac{R_1}{2R_3}\omega_1 + \frac{R_2}{2R_3}\omega_2$$

Electric motor with float stator (transmotor)



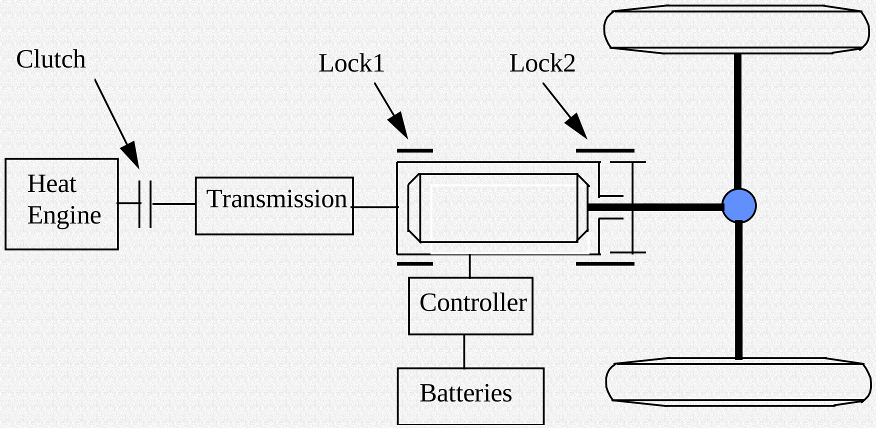
$$T_r = T_s$$

$$\omega_r = \omega_s + \omega_{rr}$$

ω_{rr} is the relative speed of the rotor to the stator

HYBRID VEHICLE DRIVE TRAIN

•Hybrid drive train with speed combination device of a transmotor



$$T_{out} = k_1 T_e = k_2 T_m$$

$$\omega_{out} = \frac{\omega_e}{k_1} + \frac{\omega_m}{k_2}$$

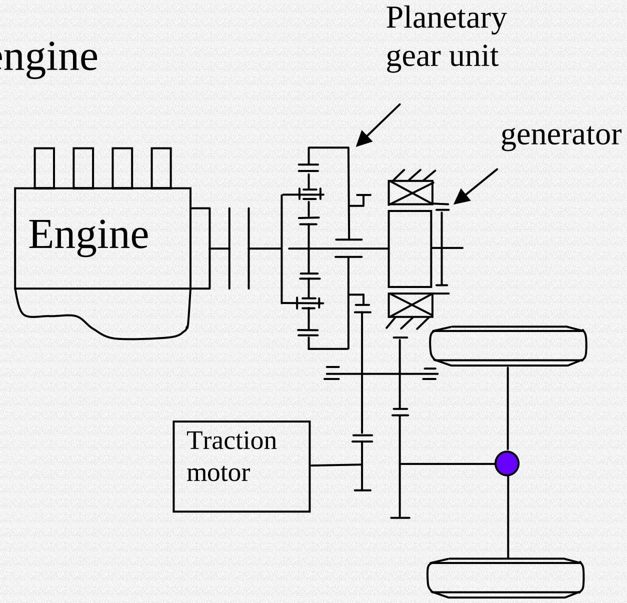
$$k_1 = k_2 = 1$$

•This drive train has the exact same operation modes as that with speed combination device of planetary gear unit, but with much simpler construction

HYBRID VEHICLE DRIVE TRAIN

•Parallel hybrid drive train with engine power splitting

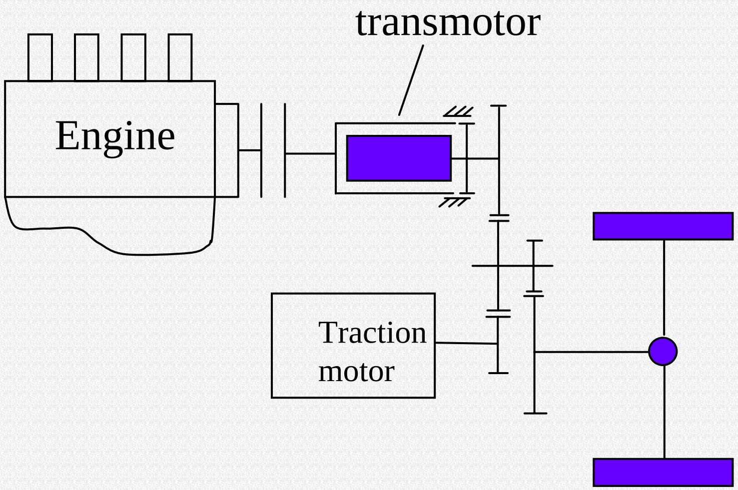
- The planetary gear unit (speed summing) can split the engine power into two parts.
- One part goes to the wheels
  another part goes to the generator
- The engine speed can be adjusted by adjusting the generator speed, so that the engine can operate in a nor raw speed region, similar as in series hybrid drive train
- The generator can also supply power to the drive train
- Better performance and fuel economy are expected
- But, suffer complicated construction and control



HYBRID VEHICLE DRIVE TRAIN

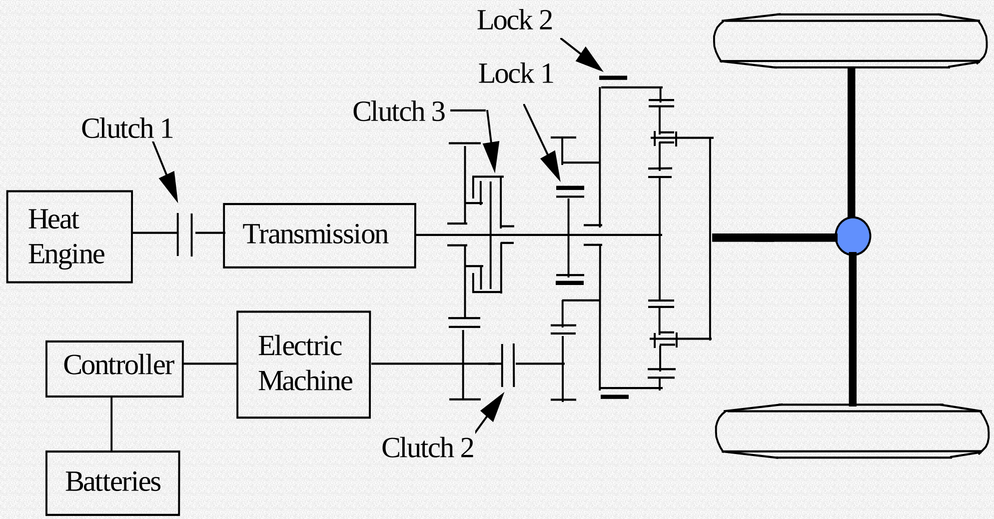
•Parallel hybrid drive train with engine power splitting using a generator with float stator (transmotor)

- •Transmotor can split the engine into two part , one part directly goes to drive train and other part to batteries
- •Transmotor functions as a generator
- •Transmotor functions as a starter
- •Adjusting the transmotor speed can adjust the engine speed so that the engine can operate in its optimal speed region
- •Transmotor can also function as a traction motor
- •Much simpler construction than using planetary gear unit and generator



HYBRID VEHICLE DRIVE TRAIN

- Integrated speed and torque combination hybrid drive train (patented by our research group)

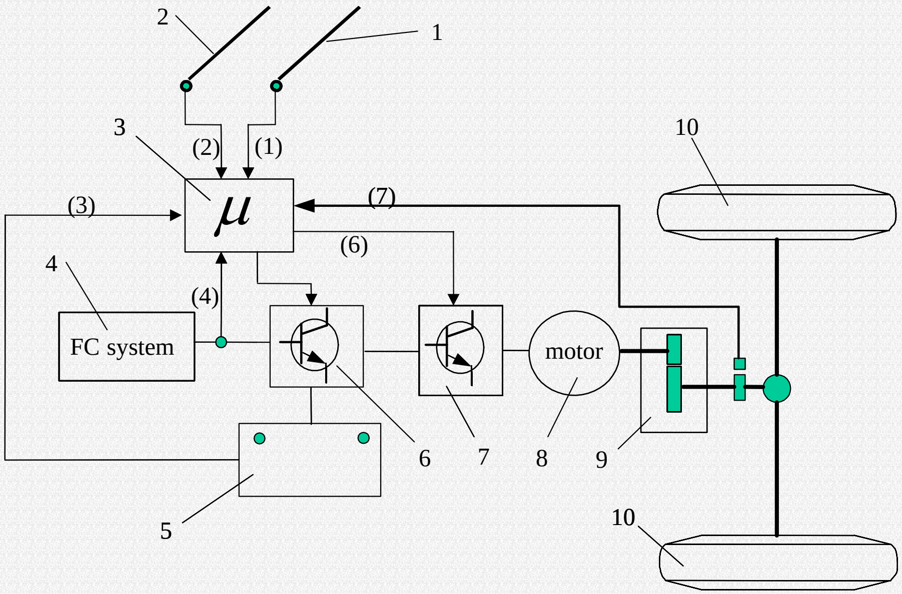


HYBRID VEHICLE DRIVE TRAIN

•Fuel Cell Powered Hybrid Drive Train

•Fuel cells supply static power

•Electric peak power source (battery/ultracapacitor) supplies dynamic power

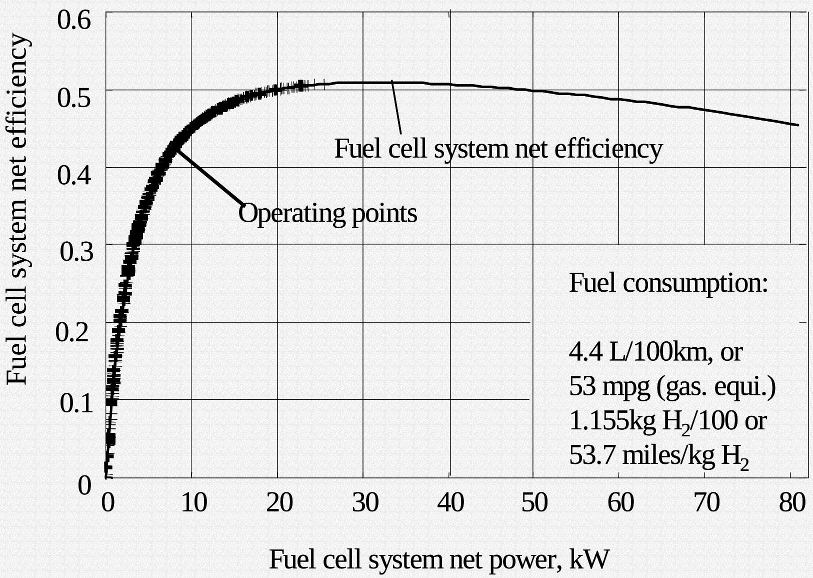


1 — Accelerator pedal, 2 — Brake pedal, 3 Vehicle controller, 4 — Fuel cell system
5 — Peaking power source, 6 — Electronic interface, 7 — motor controller
8 — Electric motor, 9 -- Transmission, 10 — Wheels
(1) -- Traction command signal, (2) -- Brake command signal,
(3) – Energy level signal in the peak power source, (4) -- Fuel cell power signal
(5) -- Electronic interface control signal, (6) -- Motor control signal (7) -- Vehicle speed signal

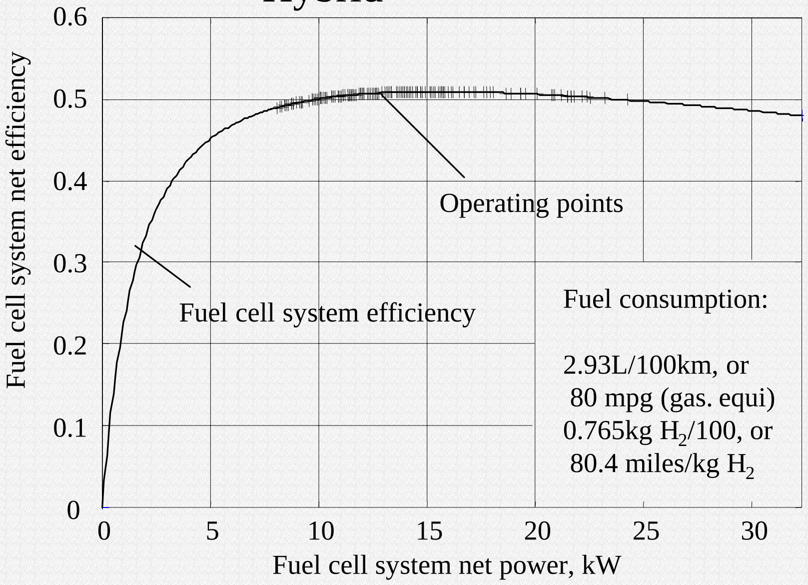
HYBRID VEHICLE DRIVE TRAIN

- **Fuel cell operating efficiency of hybrid drive train is much higher than fuel cell alone power vehicle.**

Fuel alone powered



Hybrid

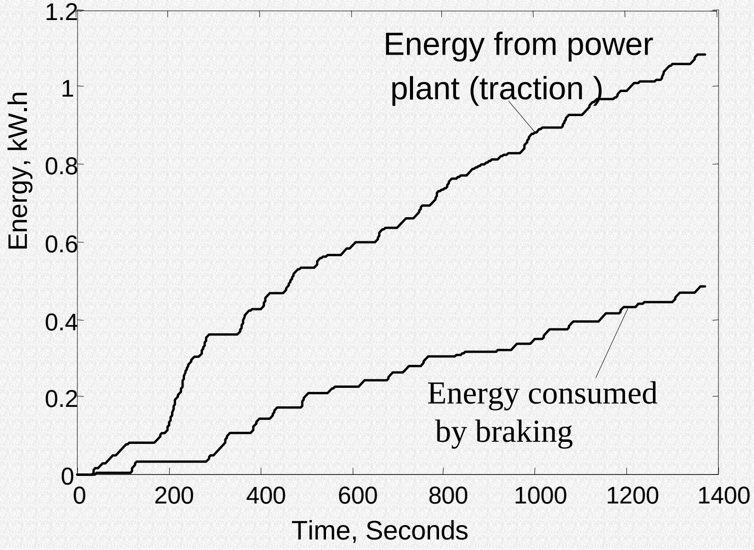


REGERATIVE BRAKING OF EV AND HEV

•In urban driving, significant amount of energy is consumed by braking

•It is expected that effective regenerative braking can significantly improve the vehicle fuel economy

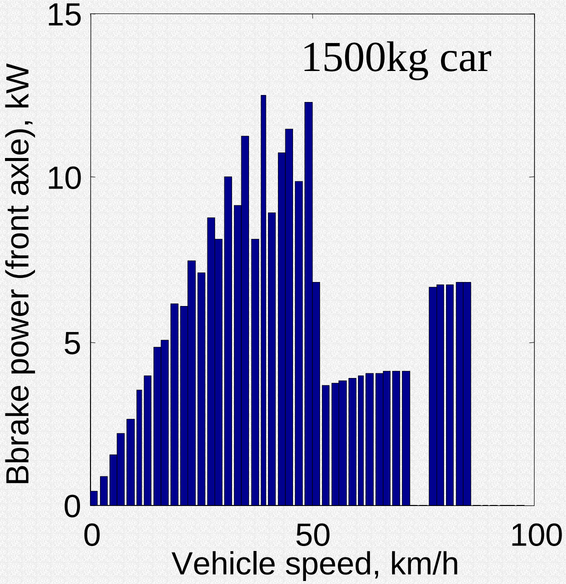
FTP urban driving cycle.

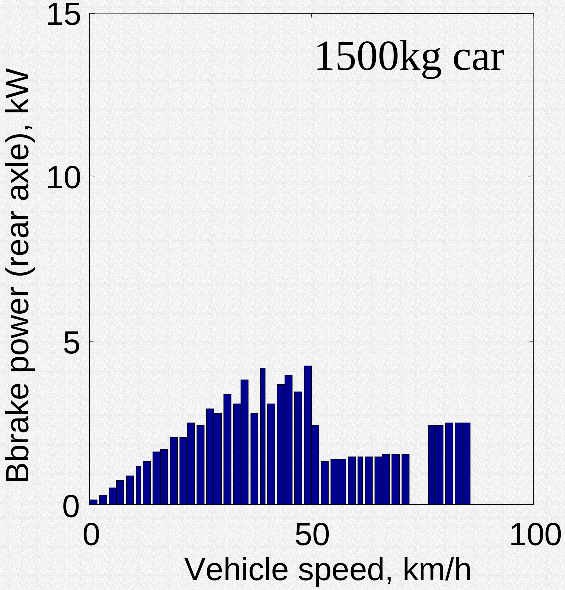


REGERATIVE BRAKING OF EV AND HEV

•In normal driving, the braking power is well in the range that the electric motor can handled.

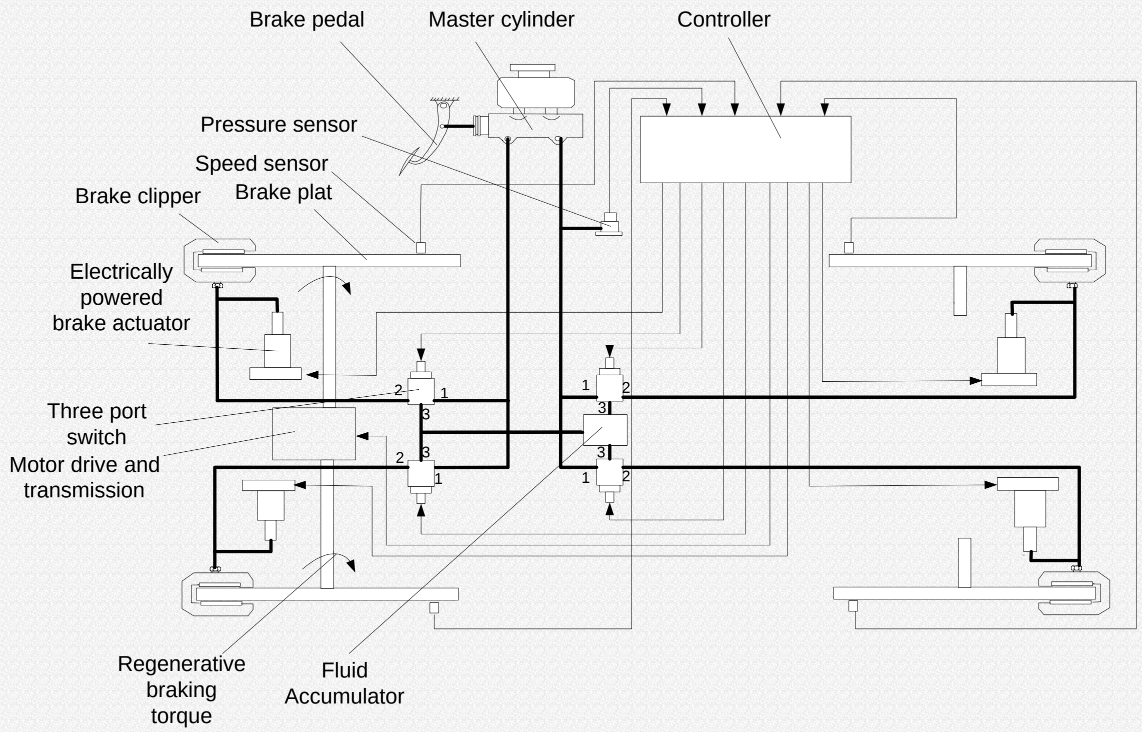
•It is expected that most of the braking energy is possibly recovered





REGERATIVE BRAKING OF EV AND HEV

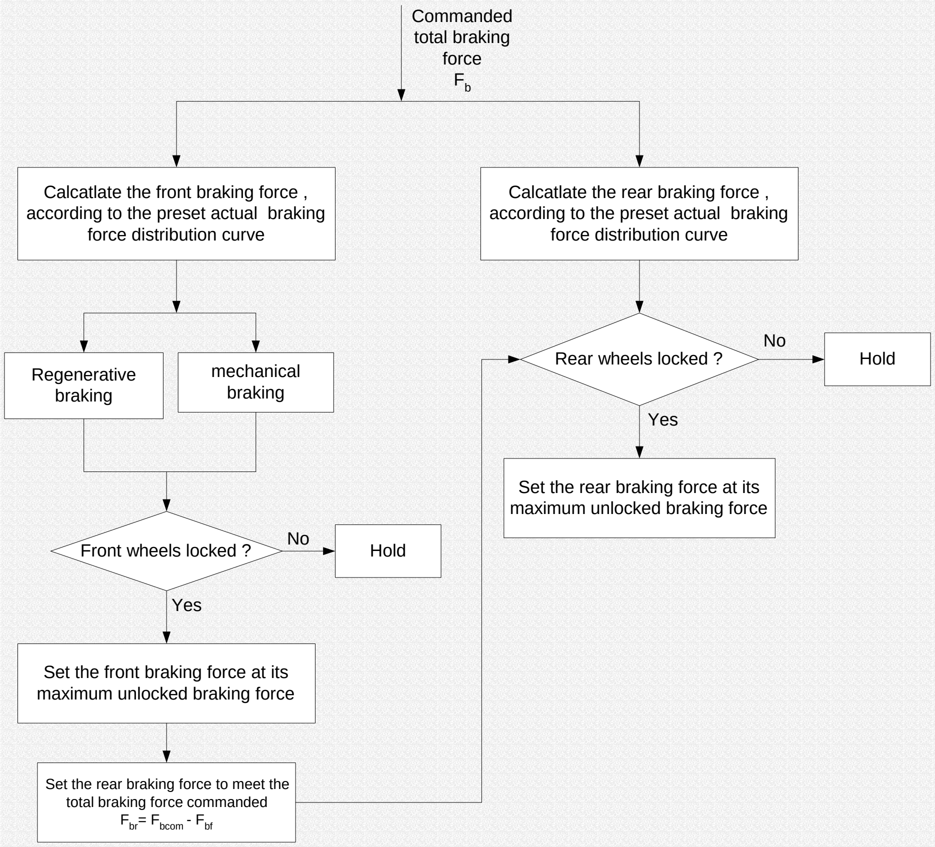
- **Hybrid braking system---mechanical and electric brake**
  - Mechanical brake is used in emergency (for safety)
  - Electric braking is used in normal braking (energy recovering)



REGERATIVE BRAKING OF EV AND HEV

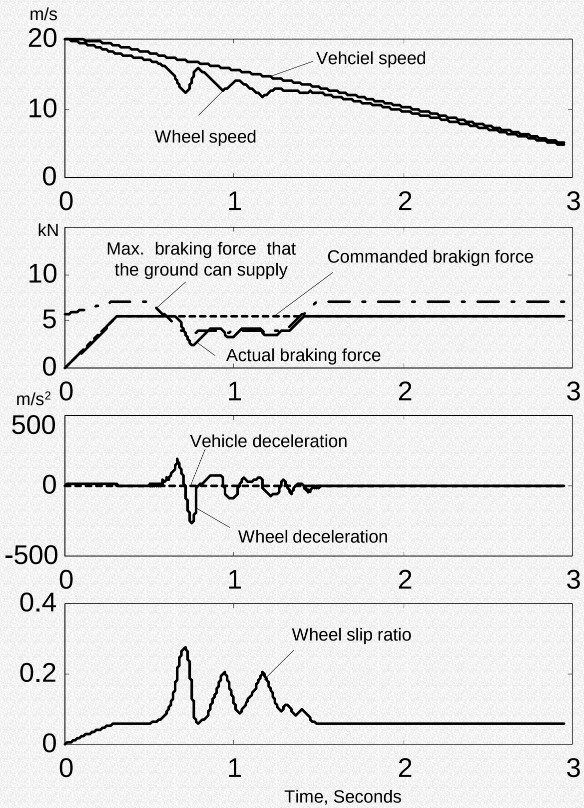
•Hybrid brake system control

- •Function as:
  - •Regenerative braking
  - •Emergency Braking
  - •Antilock braking

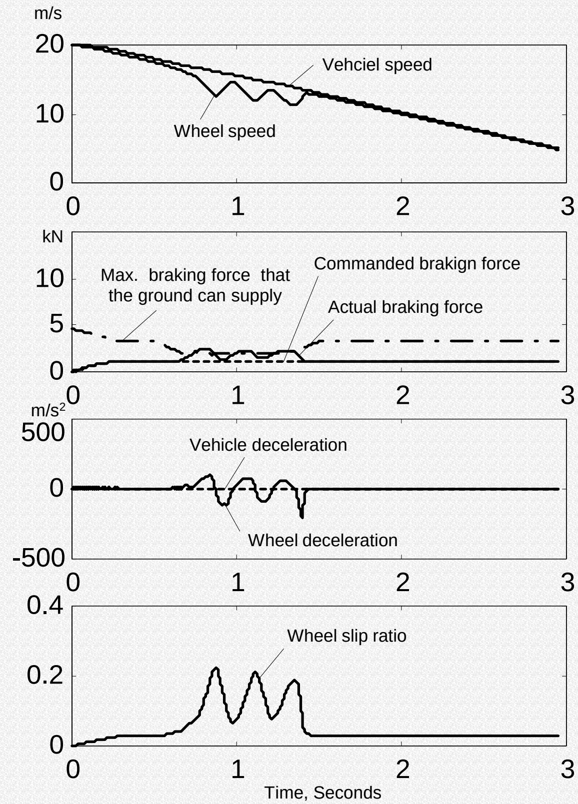


REGERATIVE BRAKING OF EV AND HEV

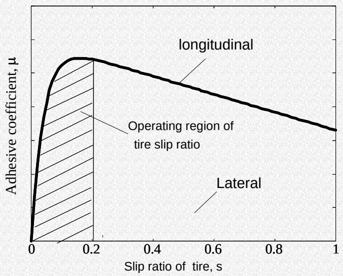
- **Antilock Braking Simulation**
  - Maintain all the wheel slip less than 25%,



Front Wheels



Rear Wheels



CONTROL STRATEGIES FOR HEV DRIVE TRAIN

•A control strategy is an algorithm, a law regulating the operation of the drive train.

•It inputs measurements of the vehicle operation (speed, acceleration, grade, etc…) and makes decisions to turn on or off certain components or to increase or reduce their power output.

•According to the preset control strategy, the drive train controller commands engine and motor to operation to produce proper torques.

CONTROL STRATEGIES FOR HEV DRIVE TRAIN

A hybrid drive train control strategy has the following objectives :

_Meeting the driver's demand for the traction power

_Minimizing the fuel consumption

Control Strategies for HEV drive train:

_Maximum state of the charge control

_Engine turn-on and turn-off control strategy

_Intelligent energy management

_Scheme based on optimal control theory

CONTROL STRATEGIES FOR HEV DRIVE TRAIN

- Maximum Battery SOC Control Strategy

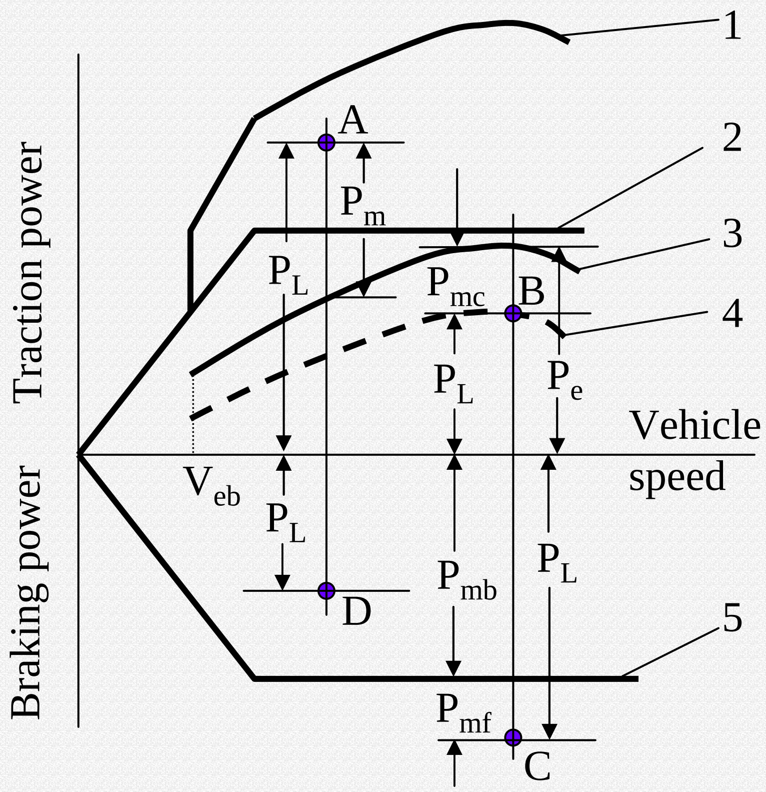
Try to maintain the battery SOC at high level by regenerative braking and engine charging

Advantage is that high power demand can be always guaranteed by high SOC battery. This is very important for some specific vehicles, such as, military vehicles

Disadvantage is that in long trip with mostly constant speed, fuel consumption would be higher, compared with other strategies

CONTROL STRATEGIES FOR HEV DRIVE TRAIN

• **Maximum battery SOC control strategy**



1—Max. power with hybrid traction mode
2—Max. motor power
3—Engine power with near full throttle
4—Partial engine power
5 --Max. motor regenerative braking power

P_L---Load power, traction or braking
P_e--- Engine power
P_m—Motor power
P_{mb}– Regenerative braking power of the motor
P_{mf}—Mechanical braking power
P_{mc}—Battery charging power
V_{eb}—Vehicle speed, below which, only electric traction available

CONTROL STRATEGIES FOR HEV DRIVE TRAIN

- **Maximum battery SOC control strategy**

Motor-alone Mode (V<Veb):

$$Pe=0$$
$$Pm=PL/Etm$$
$$Pbd=Pm/(Em.Ebd)$$

Etm: transmission efficiency from motor to driven wheels
Ebd: battery discharge efficiency
Em: motor efficiency

Hybrid Mode :

$$Pm=(PL-Pe.Ete)/Etm$$
$$Pbd=Pm/(Em.Ebd)$$

Ete: transmission efficiency from engine to the driven wheels

CONTROL STRATEGIES FOR HEV DRIVE TRAIN

- **Maximum battery SOC control strategy**

Battery Charging Mode:

$$P_m=[P_e-(P_L/E_{te})].E_{te}.E_m$$
$$P_{bd}=P_m/E_{bc}$$

Engine Alone Mode:

$$P_e=P_L/E_{te}$$
$$P_m=0$$
$$P_b=0$$

CONTROL STRATEGIES FOR HEV DRIVE TRAIN

- **Maximum battery SOC control strategy**

Regenerative Braking Mode:

Pmb=PL.Etm.Em
Pbc=Pmb.Ebc

Hybrid Braking Mode:

Pmb=Pmb,max.Em
Pbc=Pmb.Ebc

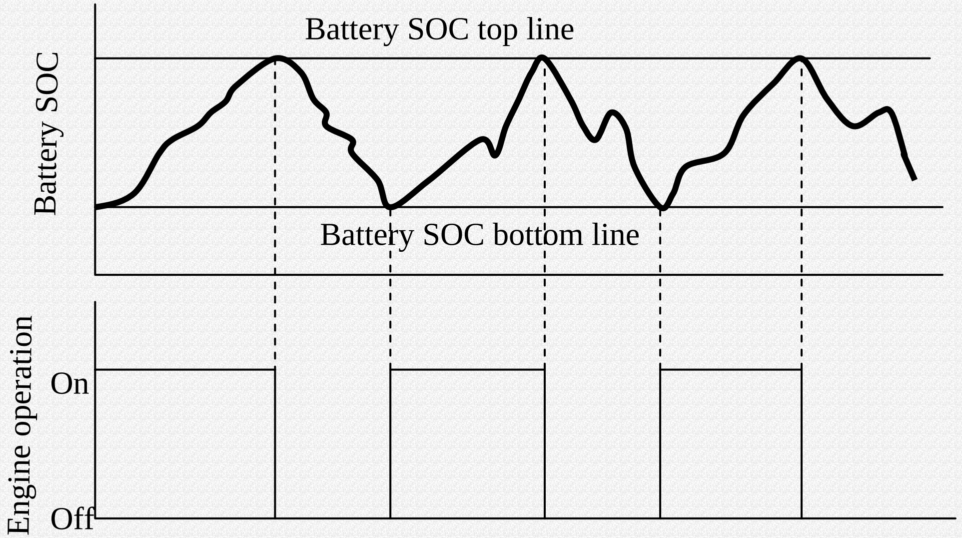
CONTROL STRATEGIES FOR HEV DRIVE TRAIN

- Engine turn-on and turn-off control strategy (Thermostatic engine control)

  - Battery SOC is always maintained between its preset top line and bottom line by turn on and turn off the engine

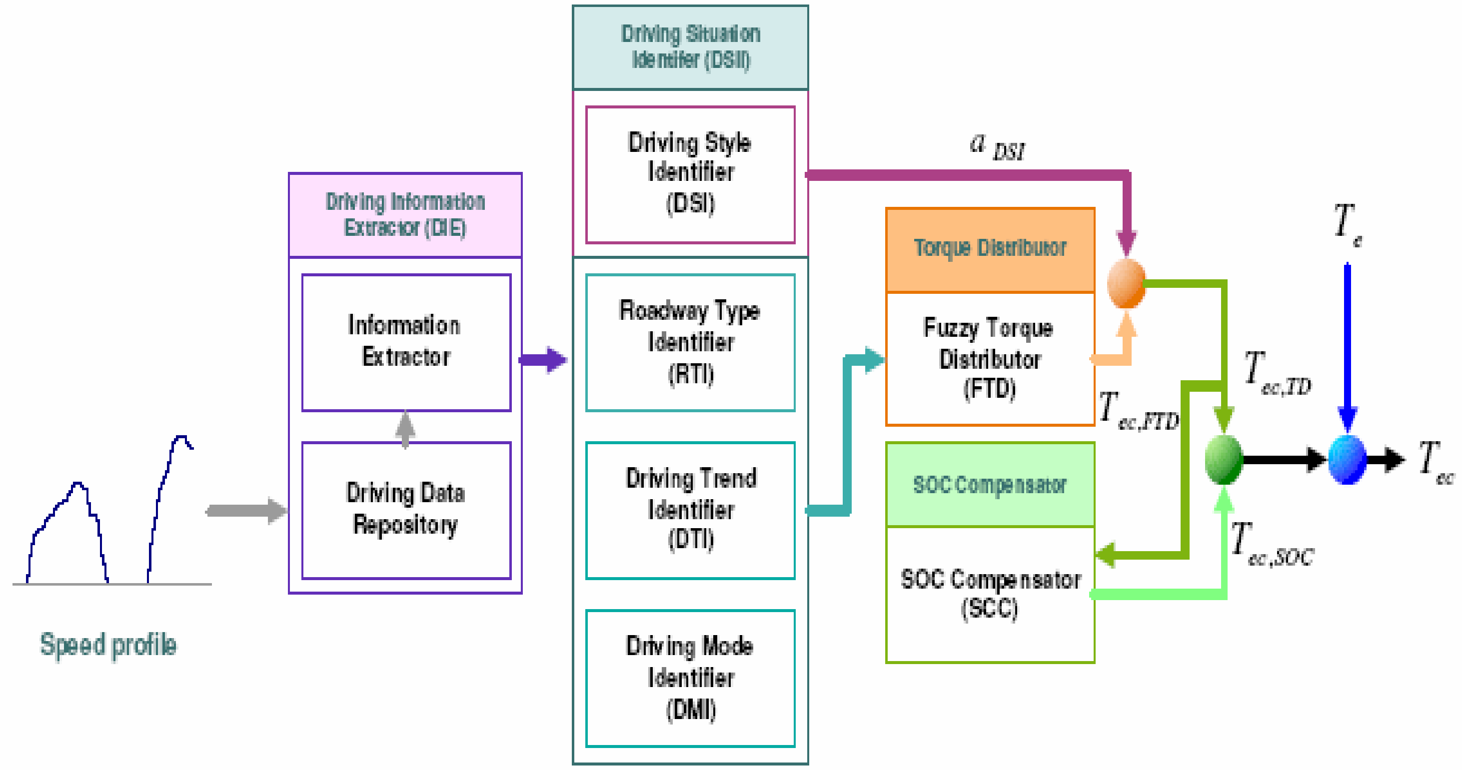
  - Advantage is that in long trip with constant speed, the engine operation can be optimized.

  - Disadvantage is that when battery SOC happens to reach bottom line and high power happens to be needed for a period, battery soc would drop too much and performance would be hurt



CONTROL STRATEGIES FOR HEV DRIVE TRAIN

- **Intelligent Energy Management**



CONTROL STRATEGIES FOR HEV DRIVE TRAIN

- Control Strategy Based on Optimal Control Theory

The problem is to minimize the following cost function

$$J = \sum_{t=0}^{N-1} \dot{m}(T_e(t), \omega_e(t)).\Delta$$

with the following constraints:

$$\omega_{e\_\min} < \omega_e(t) < \omega_{e\_\max}$$

$$0 < \omega_m(t) < \omega_{m\_\max}$$

$$T_{m\_\min}(\omega_m(t)) < T_m(t) < T_{m\_\max}(\omega_m(t))$$

$$0 < T_e(t) < T_{e\_\max}(\omega_e(t))$$

CONTROL STRATEGIES FOR HEV DRIVE TRAIN

- Control Strategy Based on Optimal Control Theory

And

$$x(N) - x(0) = \Delta SOC$$

While the state of the charge of the battery, x(t), is updated as following

$$x(t+1) = x(t) + P_m(T_m(t), \omega_m(t)).\Delta$$

Where

$\dot{m}(T_e(t), \omega_e(t))$: Fuel consumption required producing torque $T_e(t)$ at speed $\omega_e(t)$

$P_m(T_m(t), \omega_m(t))$: Power required producing the torque $T_m(t)$ at speed $\omega_m(t)$

CONTROL STRATEGIES FOR HEV DRIVE TRAIN

- Control Strategy Based on Optimal Control Theory

ΔSOC : is the desired electric energy consumption over the speed cycle

$T_e(t)$: IC engine torque

$T_m(t)$: Electric motor torque

$\omega_e(t)$: IC engine speed

$\omega_m(t)$: Electric motor speed

CONTROL STRATEGIES FOR HEV DRIVE TRAIN

• Braking Strategies:

_ Series Braking Optimal Feel:

The controller determines the fron/rear balance that will minimize the stopping distance and optimize the driver's feelings.

_Series Braking Optimal Energy Recovery:

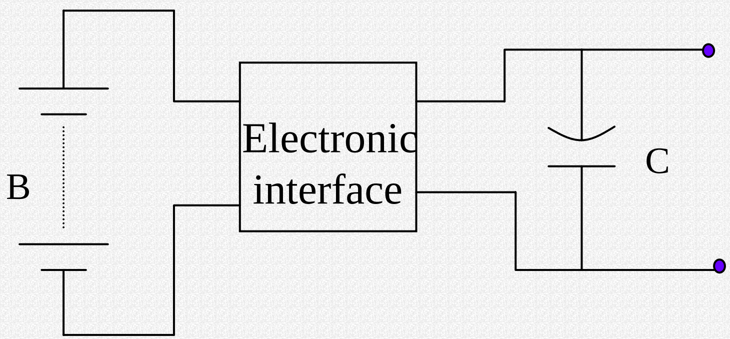
The braking balance is such that the maximum kinetic energy is recovered.

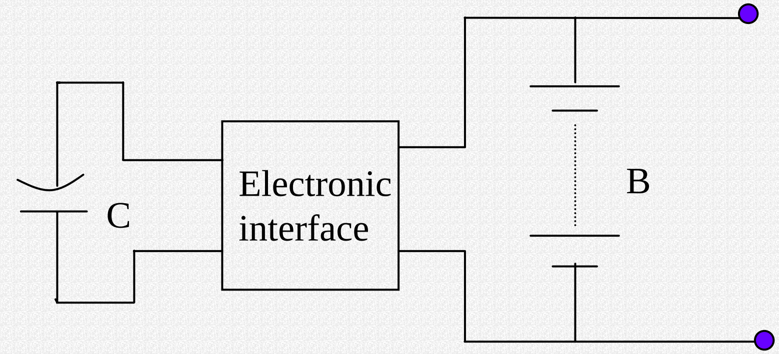
_Parallel Braking:

The electric braking system supplies the additional braking force to the mechanical system with a fixed relation.

ELECTRIC ENERGY STOARGE

- Hybrid electric energy storage with battery and ultracapacitor
  - Ultracapacitor supplies peak power
  - Battery supplies energy



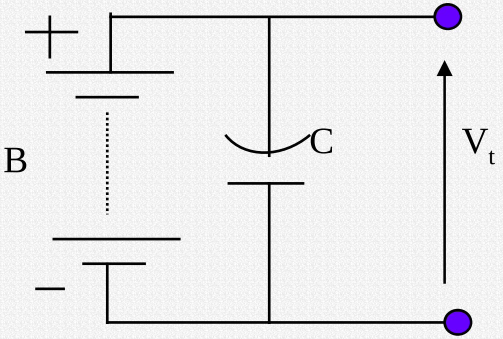


The DC bus voltage is equal to the ultracapacitor voltage
The battery current can be controlled
Terminal voltage varies with large magnitude

The DC bus voltage is equal to the battery voltage
The ultracapacitor current can be controlled
Terminal voltage varies with small magnitude
Capacitor’s energy storage can be fully used

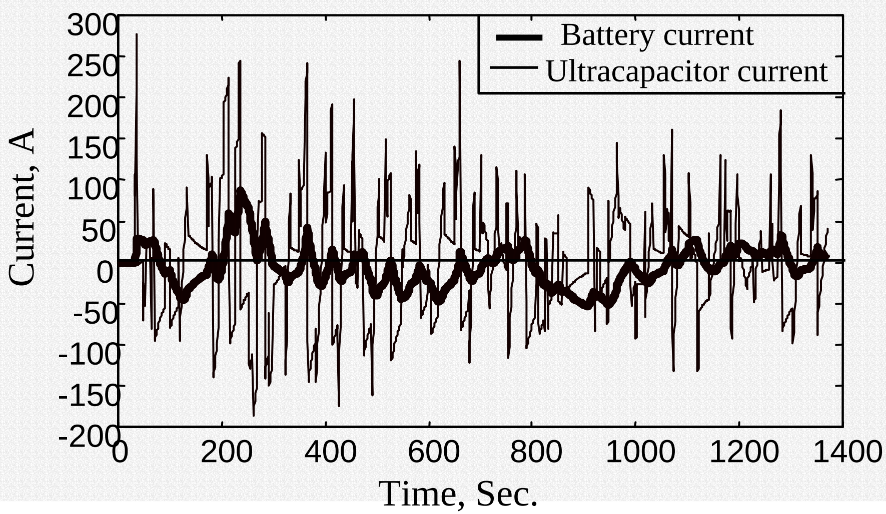
ELECTRIC ENERGY STOARGE

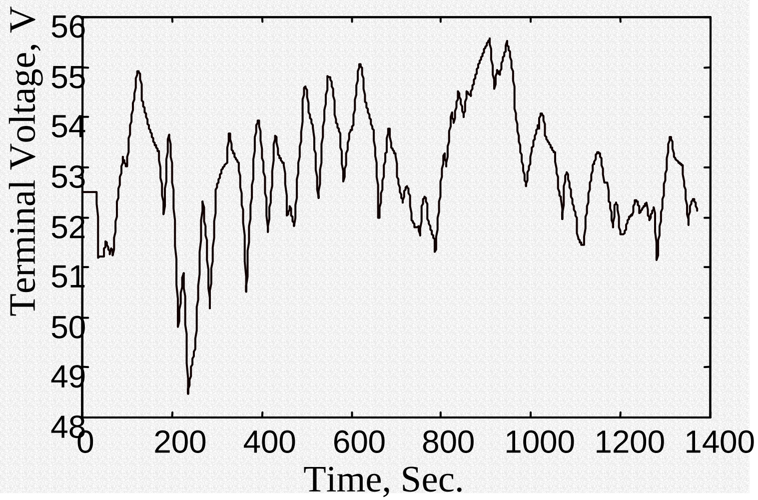
Directly connected batteries and Ultracapacitors



Advantages: simple construction and low cost

Disadvantages: Energy flow from the batteries and ultracapacitors is uncontrollable





BASIC REQUIEMENTS TRACTION MOTOR FOR EV AND HEV

•Good speed-torque (power) characteristics that is close to “ideal”characteristics

•High efficiency

•High specific power (power per unit weight)

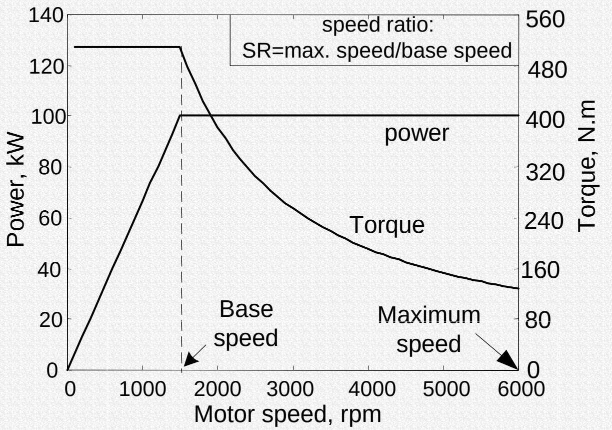
•High reliability and ruggedness

•Safety

•Low cost

BASIC REQUIEMENTS TRACTION MOTOR FOR EV AND HEV

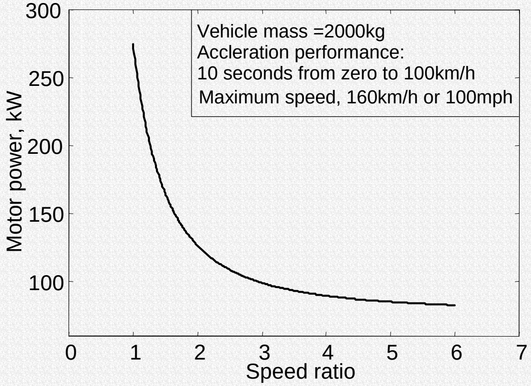
- **The impact of speed-torque characteristics to the motor power rating**



- Electric motor usually has a characteristics close to be "ideal" for traction. Thus, single gear transmission is used

- The typical data that represents the motor chrematistics is the speed ratio (maximum speed/base speed)

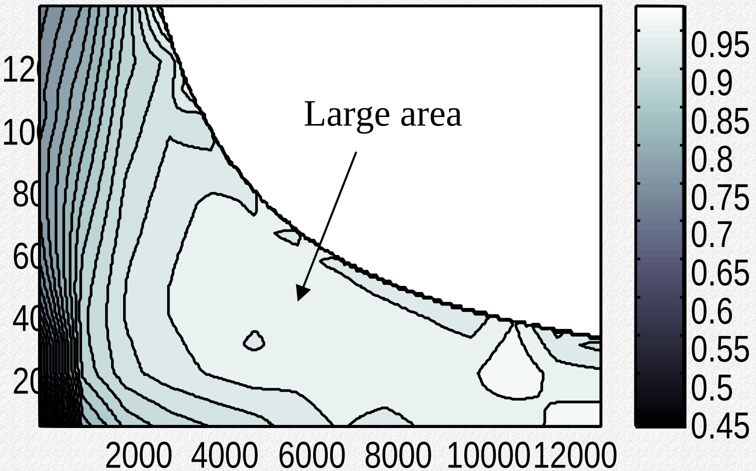
- For a given acceleration performance, increasing the speed ratio (reduce the base speed or extend the constant power region) can significantly reduce the power rating of the traction motor

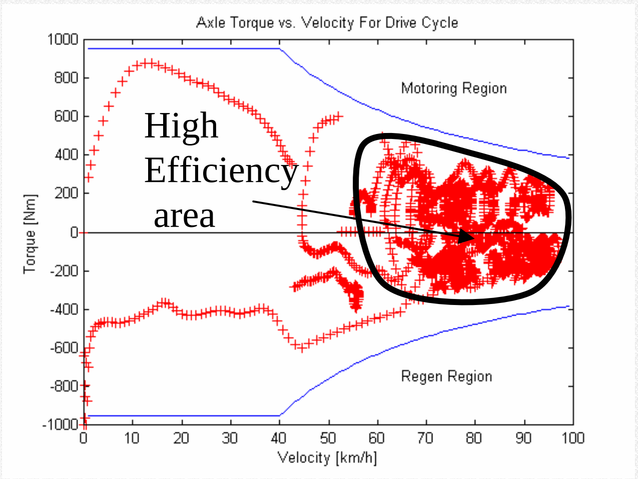


- Speed ratio of 4 may be the proper design. Further increase beyond that will reduce the motor power rating slightly and the maximum torque may be over the torque limited by the friction between tire and road and cause tire slip on the ground

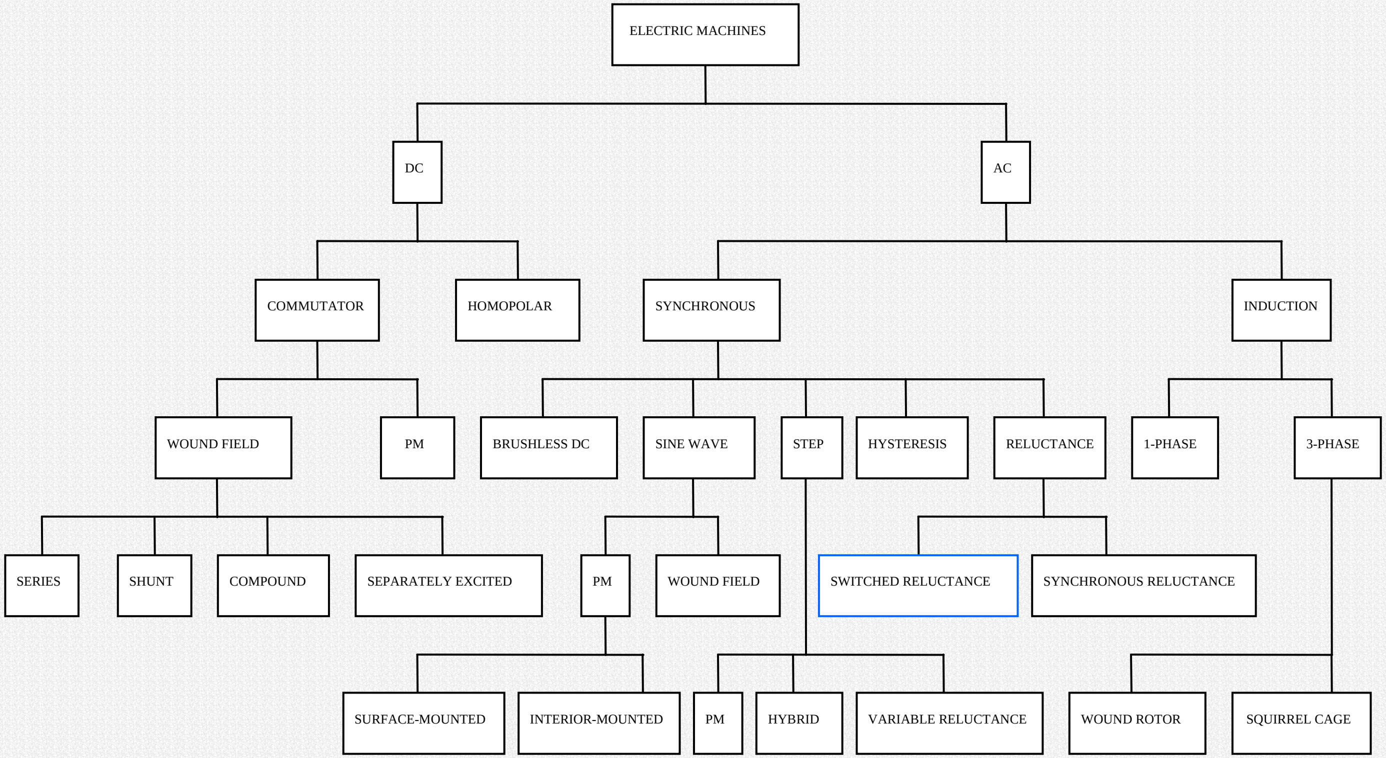
BASIC REQUIEMENTS TRACTION MOTOR FOR EV AND HEV

- **High efficiency**
  - High peak efficiency (maximum value)
  - More important is the large high efficiency area
  - And coinciding high efficiency area with mostly operating area





COMMONLY USED MOTOR DRIVES



CLASSIFICATION OF ELECTRIC MACHINERY

COMMONLY USED MOTOR DRIVES

- DC Motor Drive
- Permanent Magnet Motor Drive
- Induction Motor Drive
- Switched Reluctance Motor Drive

COMMONLY USED MOTOR DRIVES

- **DC Motor Drive**

  - Advantages:

    -Simple and Low Cost Converter Topology
    -Simplicity in Control

  - Disadvantages:

    -Requirement of Maintenance
    -Difficulty for High Current, High Voltage Application
    -Limited di/dt due to the Brush
    -Unacceptable in some Environments

COMMONLY USED MOTOR DRIVES

- **Permanent Magnet Motor Drive**

  - Advantages:

    -High Torque and Power Density
    -High Efficiency

  - Disadvantages:

    -High Cost
    -Difficulty for Field Weakening Operation
    -Difficulty for High Speed Low Voltage Operation
    -Lock Rotor Problem
    -Possibility of Demagnetization at High Temperature or Under Fault

COMMONLY USED MOTOR DRIVES

- **Induction Motor Drive**

  - Advantages:

    -Low Cost

    -Low Torque, Noise and Vibration

  - Disadvantages:

    -Complexity in Control

    -Difficulty for High Power Low Voltage Operation

    -Possibility of Mechanical Failure of the Rotor Winding

COMMONLY USED MOTOR DRIVES

- **Switched Reluctance Motor Drive**

  - Advantages:

    -Low Cost and Rugged Motor Structure
    -Reliable Converter Topology
    -Simplicity in Control
    -High Speed Operation Capability

  - Disadvantages:

    -Torque Ripple, Vibration and Noise
    -Requirement of Rotor Position Information

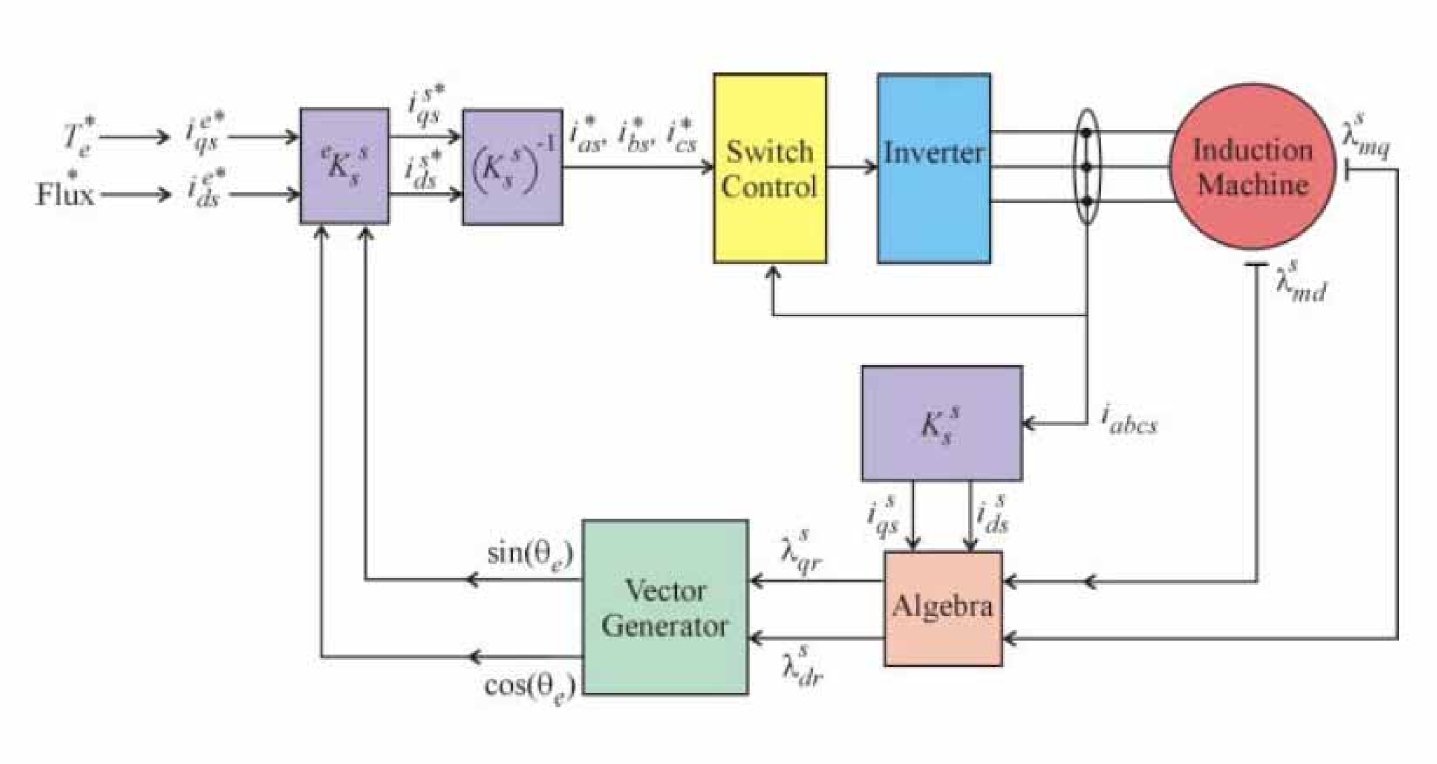
COMMONLY USED MOTOR DRIVES

- Comparison Between Different Motor Drives

	IM	BLDC		SRM
		SM	IPM	
Robustness	+			+
Motor Cost	+			+
Efficiency		+	+	
Open-loop Control	+		+	
Closed-loop Simplicity		+		+
Torque Ripple	+		+	-
Wide Speed Range	+			++
No Position Sensor		-	-	-
Acoustic Noise				-

CONTROL OF IM DRIVE FOR TRACTION

- Direct Method of Vector Control for Induction Motor Drive



CONTROL OF IM DRIVE FOR TRACTION

- Indirect Method of Vector Control for Induction Motor Drive