CONTROL OF H.E.V USING FUZZY LOGIC

FINAL-SEMESTER PRESENTATION

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HYBRID ELECTRIC VEHICLE

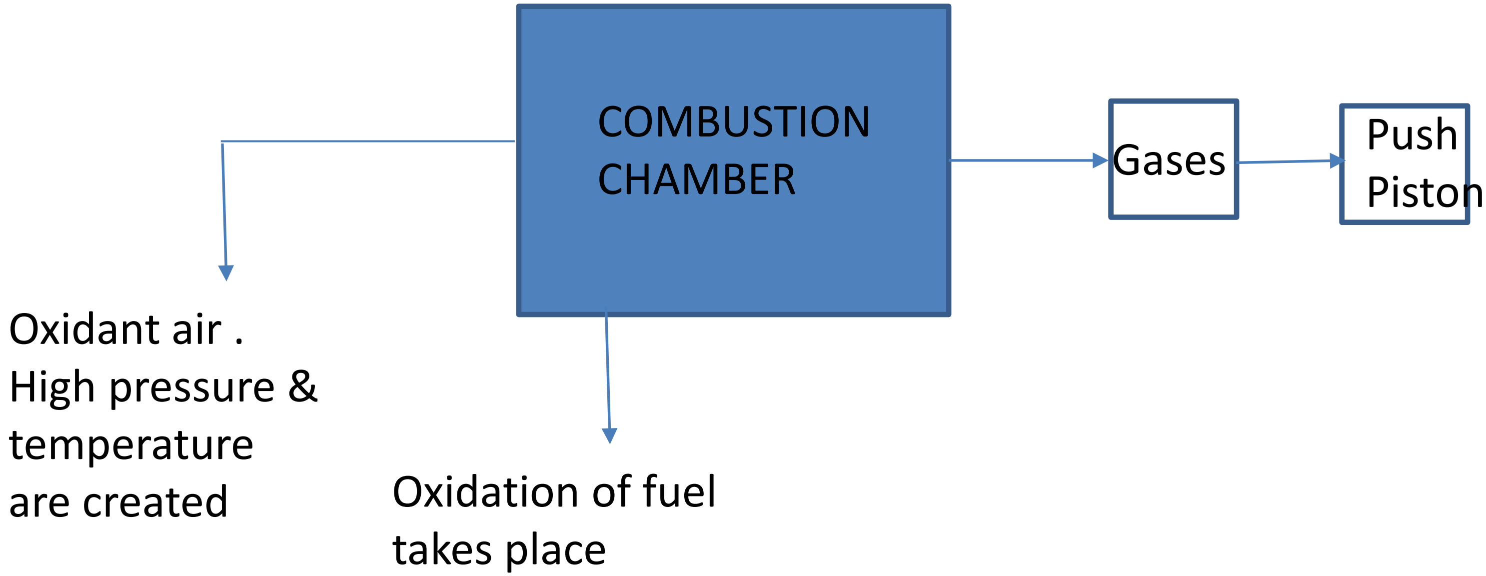
HYBRID VEHICLE

Run on two or more distinct power sources

ELECTRIC VEHICLE

Run on one or more Electric Motor

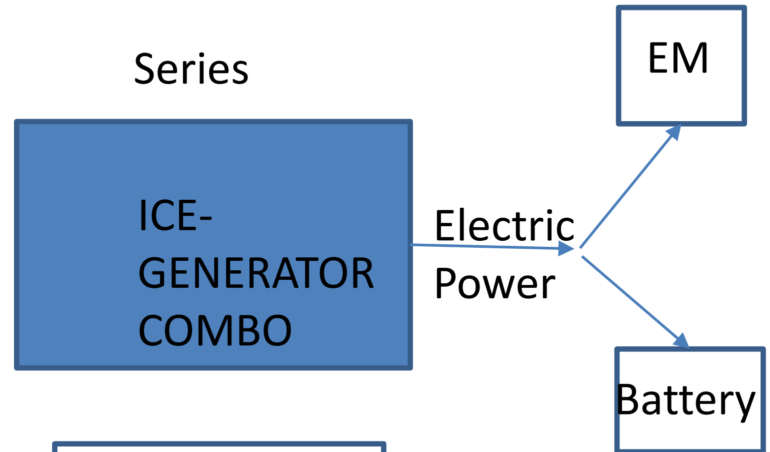
INTERNAL COMBUSTION ENGINE



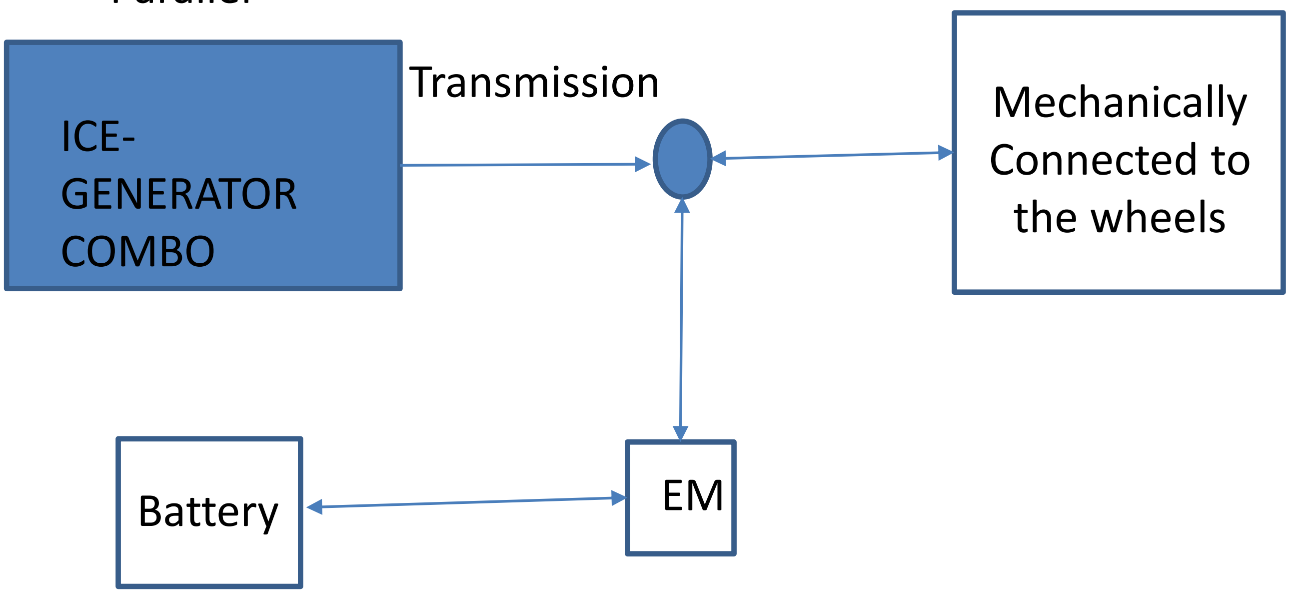
Types of HEV

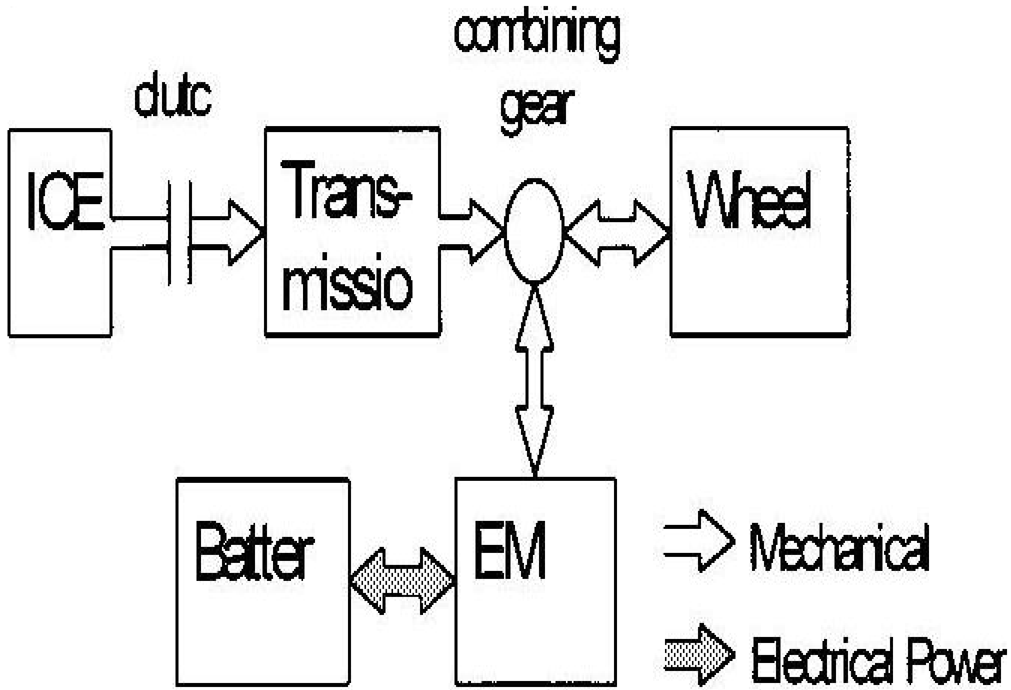
- Series
- Parallel
- Dual

Series



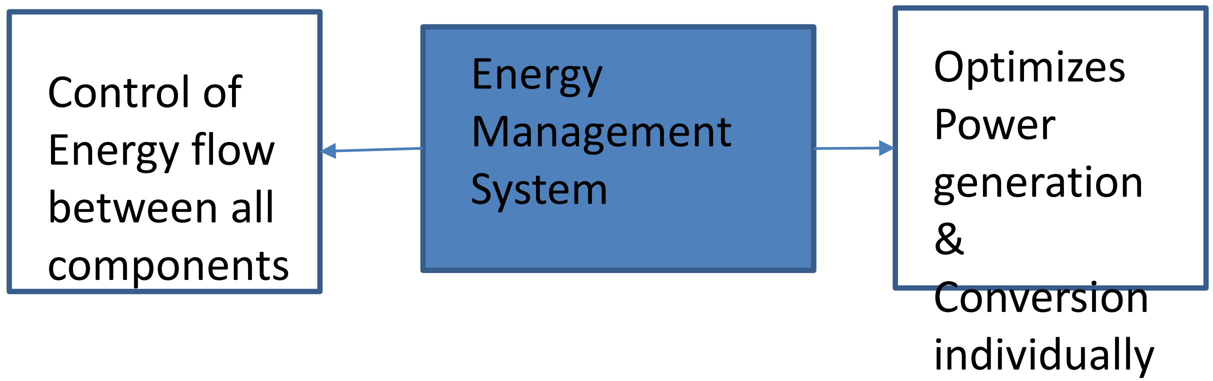
Parallel





- Power to wheel by ICE
- Power to wheel by EM
- Power to wheel by ICE & EM simultaneously
- Charge the battery, using part of ICE power to drive the EM as a generator (the other part of ICE power) is used to drive wheels
- Slow down the Vehicle by letting wheels drive the EM as a generator that provides power to the battery (regenerative braking)

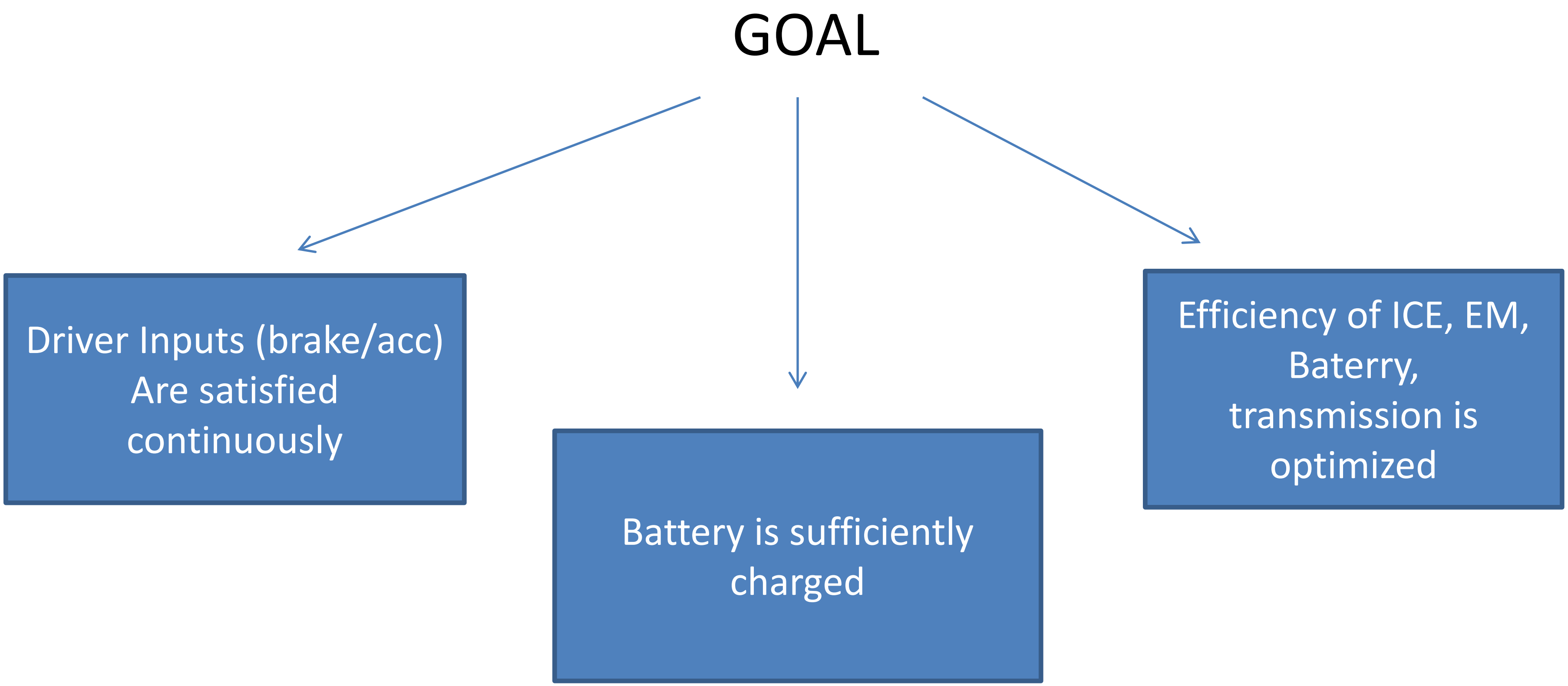
Power Controller



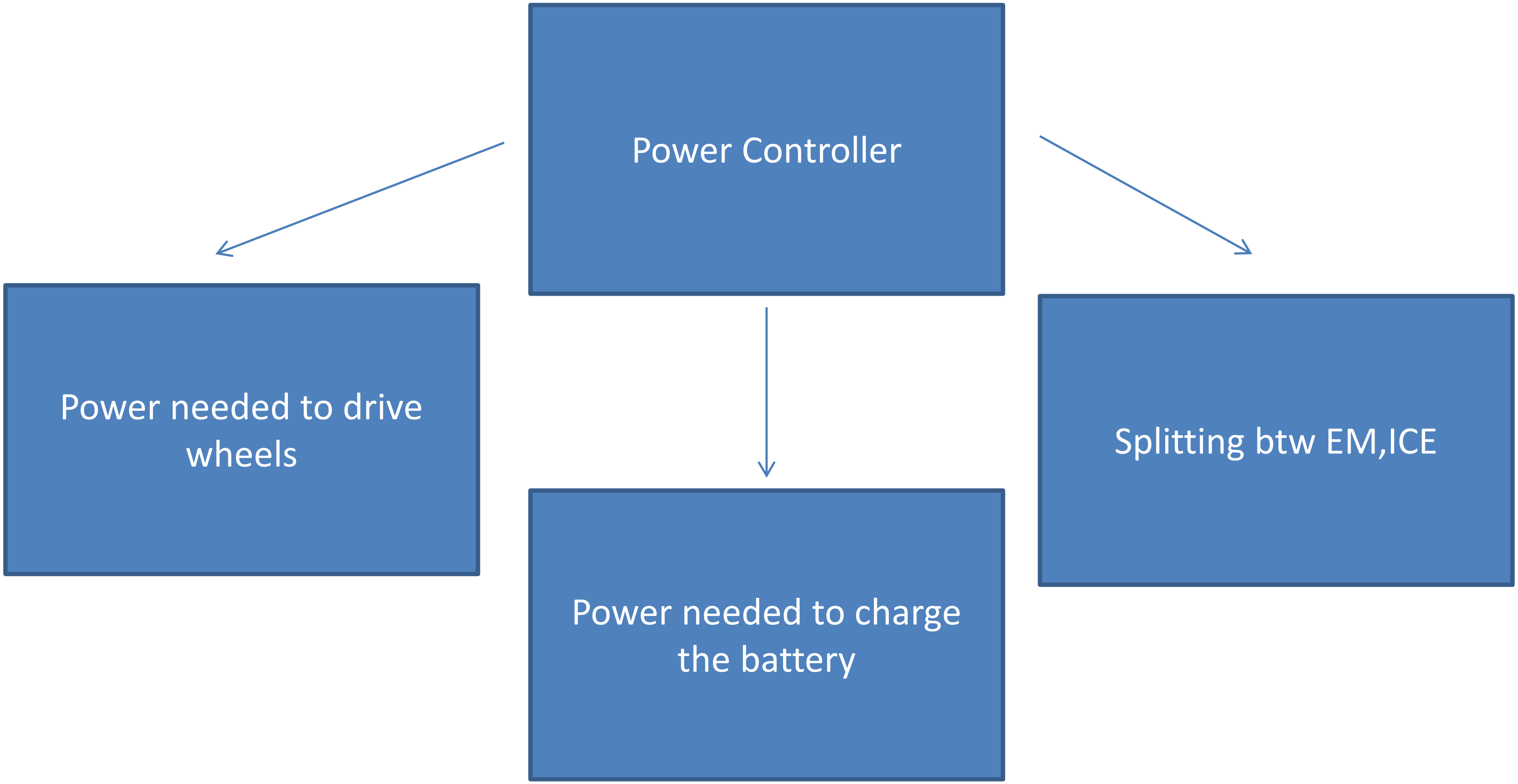
Fuzzy logic

- Imprecise measurements
- Component Variability
- Rule based Energy management Statergy.

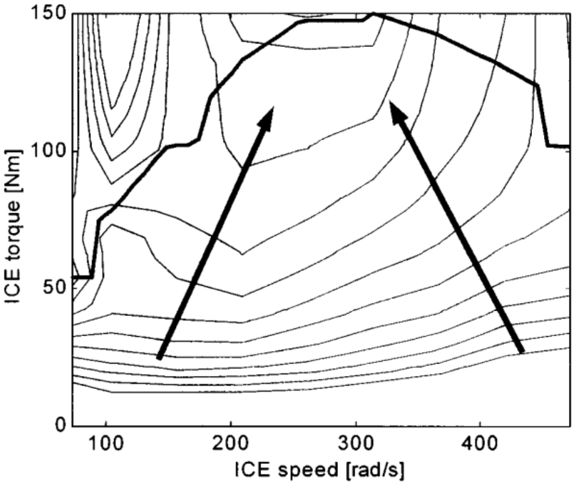
SECTION-III:ENERGY MANAGEMENT STRATERGY



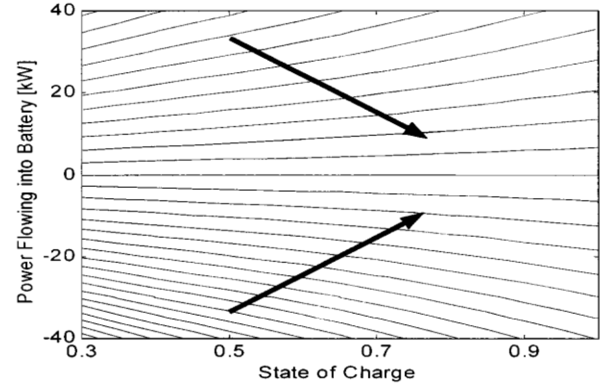
Power Controller



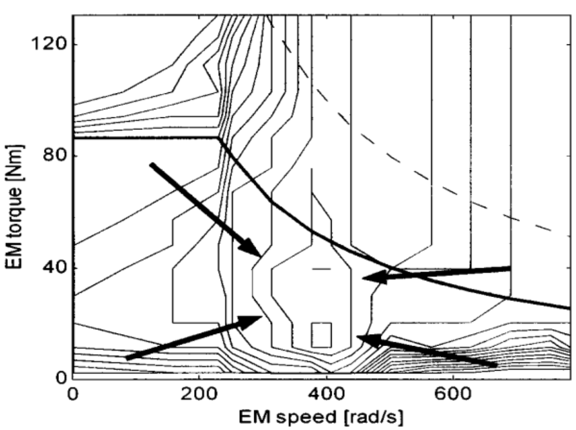
A.Efficiency Maps



ICE Power should not be (<=6KW or >=50KW)
Torque: Throttle angle
Speed: Shifting Gear

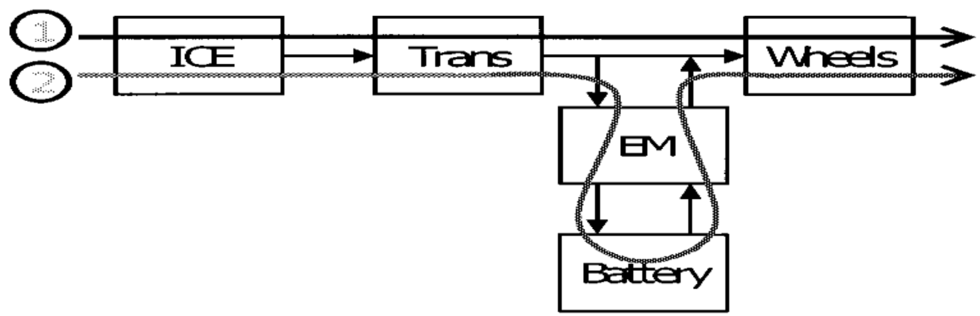


High SOC
Low Power Level



EM speed can't be gear shifted so, Optimize power at given speed

B. Power Split Strategy



Loses associated with path-2

1.Efficiency of EM : 1st as generator ; 2nd motor
2.Efficiency of Baterry:1st to store; 2nd to release

After calculations

Advisable to use path 2 over path 1
only when
path 1 is 16% less efficient than path 2

a) Power level < 6KW
Only EM

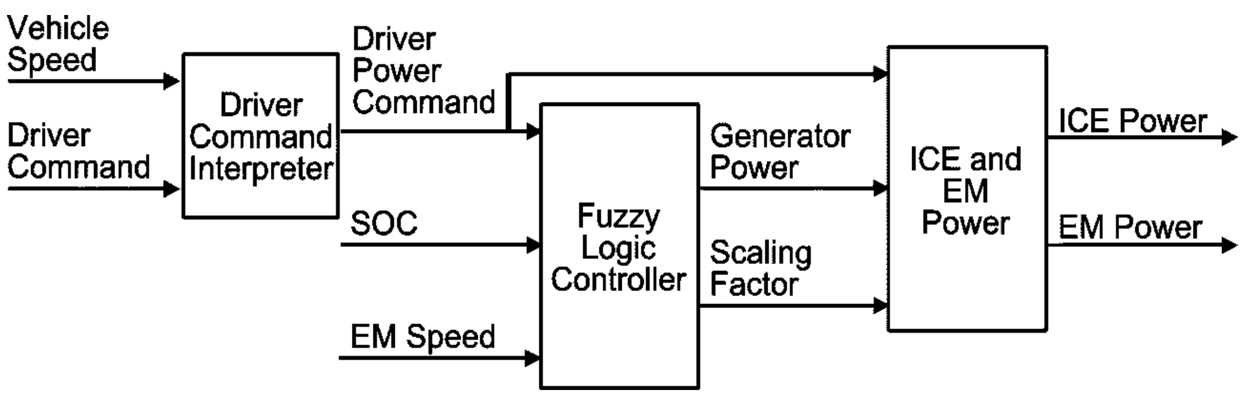
b) Power Level 6-50 KW
Only ICE

c) Power level >50KW
EM to complement
ICE

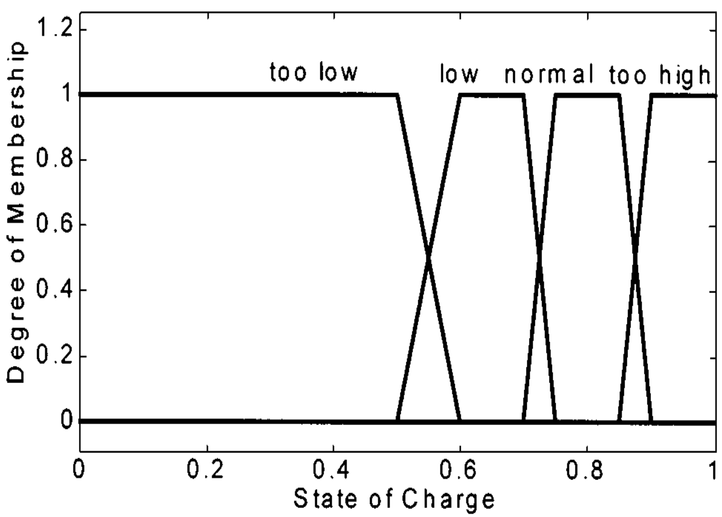
Section IV: Fuzzy Logic Controller

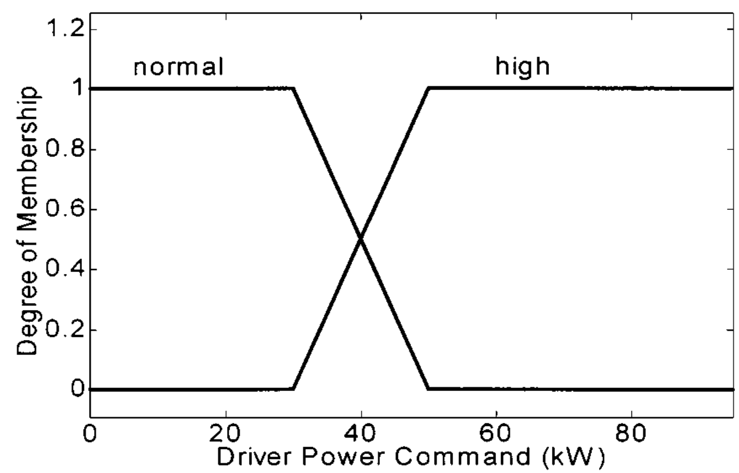
Antecedent
1.SOC
2.P-driver
3. Speed -EM

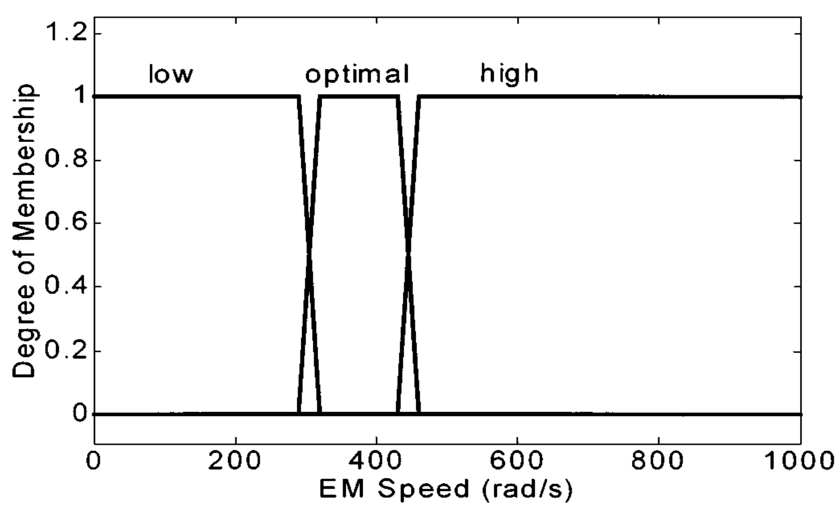
Precedent
1.P-gen
2. Scaling Factor



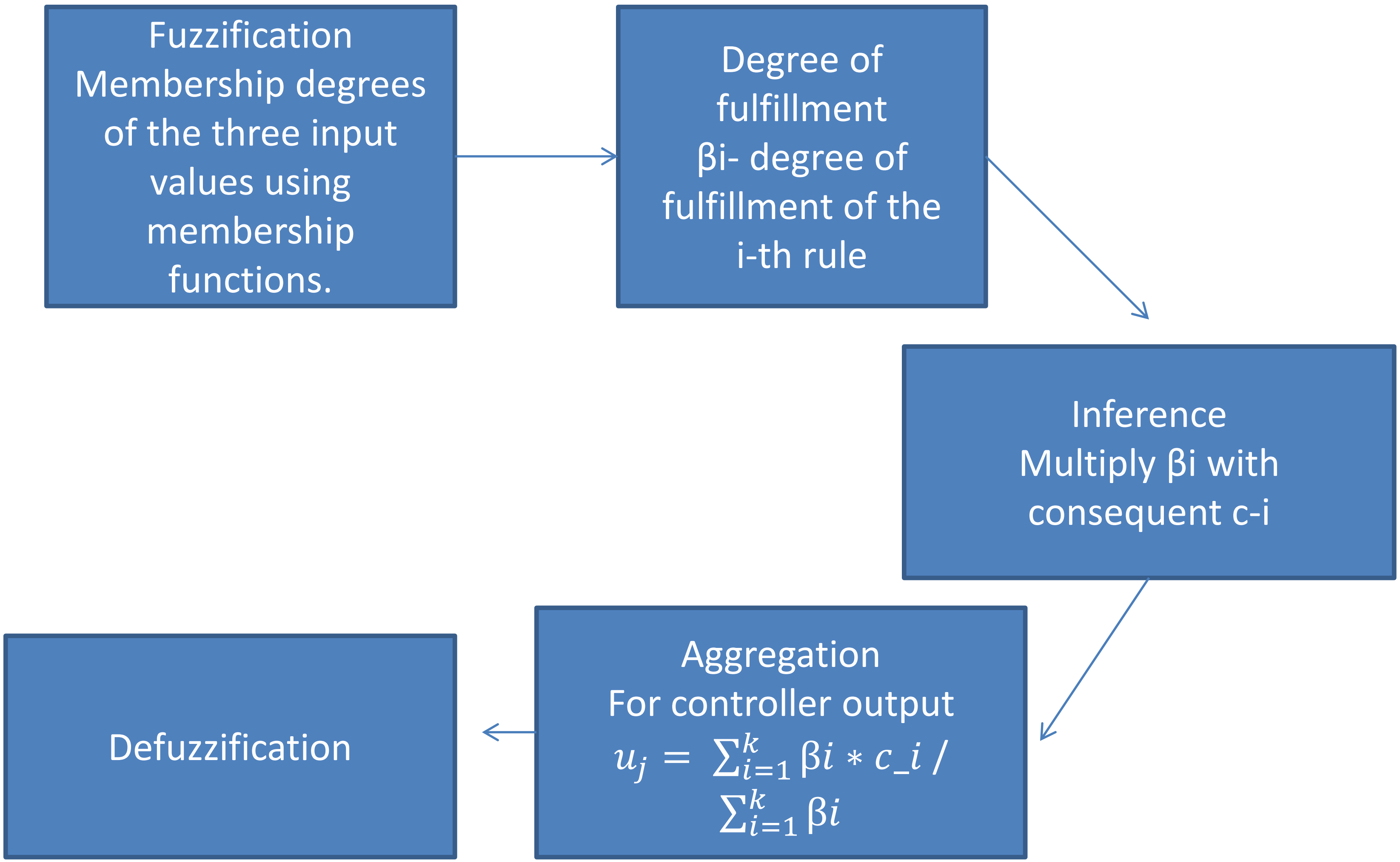
Membership Functions



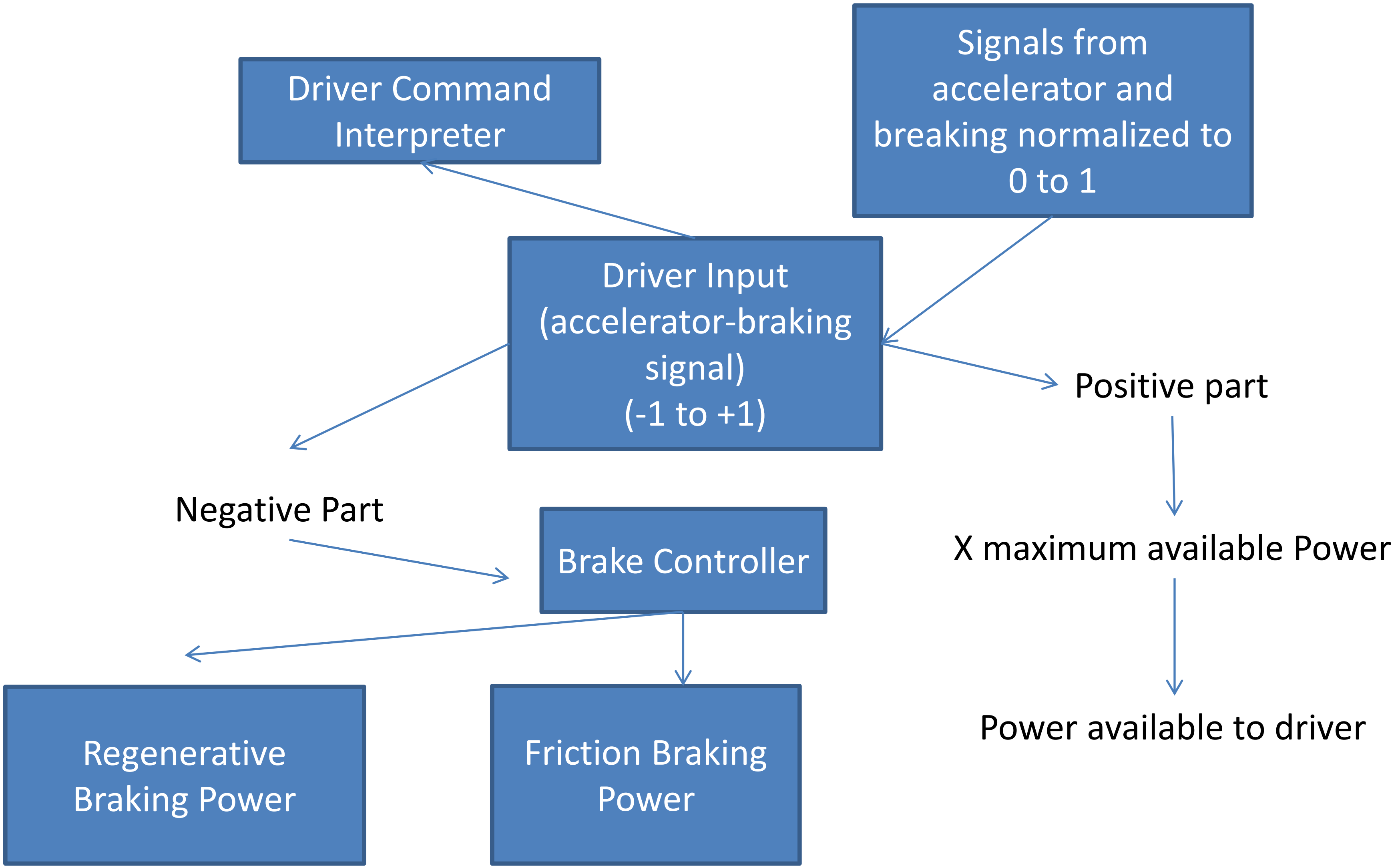




STEPS

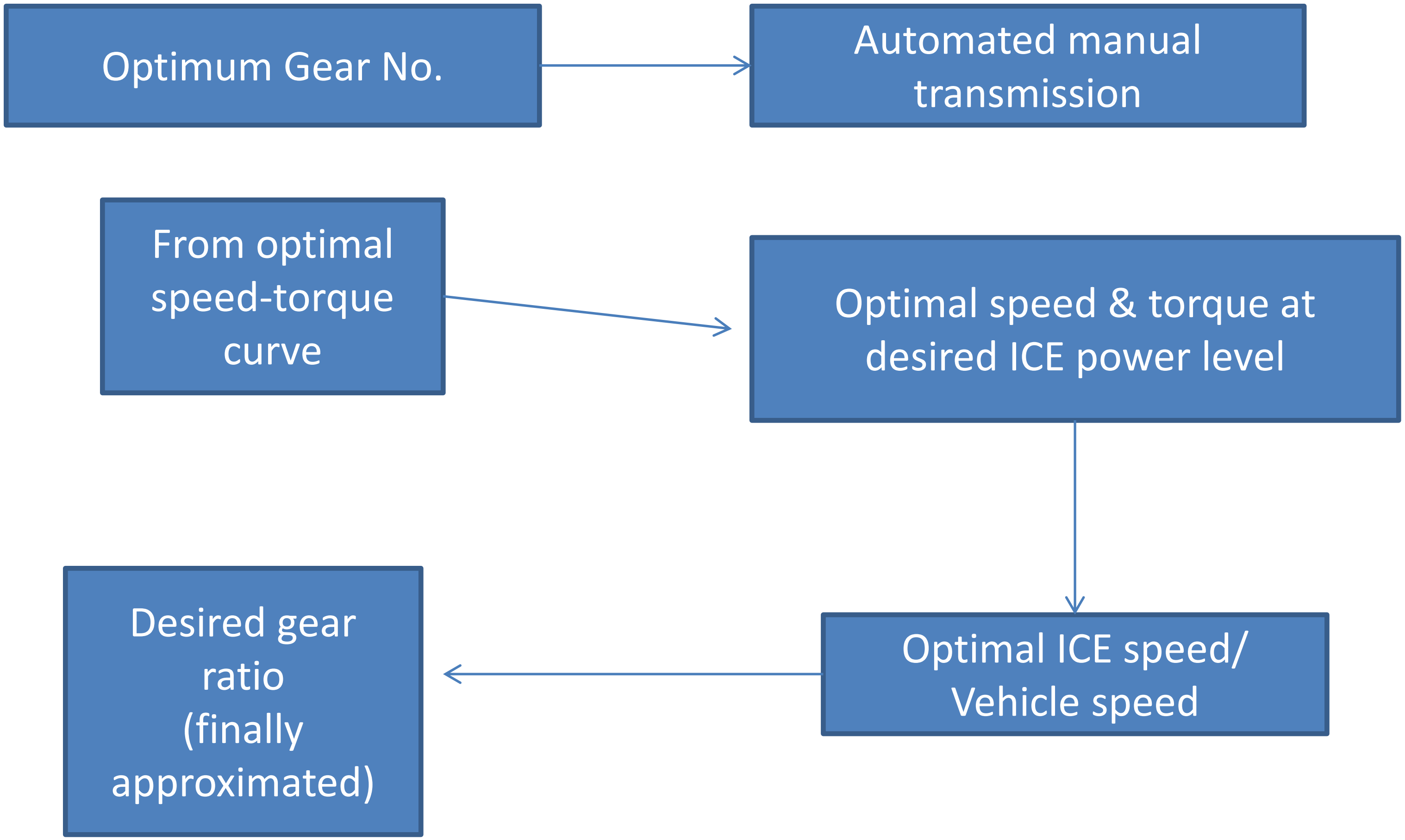

Fuzzification
Membership degrees of the three input values using membership functions.
Degree of fulfillment
βi- degree of fulfillment of the i-th rule
Inference
Multiply βi with consequent c-i
Aggregation
For controller output
$u_j = \sum_{i=1}^{k} \beta i * c\_i \, / \, \sum_{i=1}^{k} \beta i$
Defuzzification

B.Power Controller



Cannot exceed 65% of the total braking power

C. Gear Shifting Control



Mathematical Model for
a)Vehicle speed
b)Power required

Topics Covered

1)General description of vehicle movement

2)Vehicle resistance

3)Dynamic equation

4)Tire Ground Adhesion

AIM

- Fundamental: Apply Newton's second law
  Acceleration of object $\propto$ Net external force.

- Acceleration of the Vehicle depends on:

1) Power delivered by the propulsion unit
2) Road conditions
3) Aerodynamics of the vehicle
4) Composite mass of the vehicle

General description of vehicle movement

- Forces acting are
  1) Tractive force ($\mathbf{F_t}$) - produced by the power plant of the vehicle.
- Resistive forces are
  1)Rolling resistance
  2)Aerodynamic drag
  3)Uphill resistance

$$\frac{dV}{dt} = \frac{\sum F_t - \sum F_{resistac}}{\delta M}$$

where

V = vehicle speed

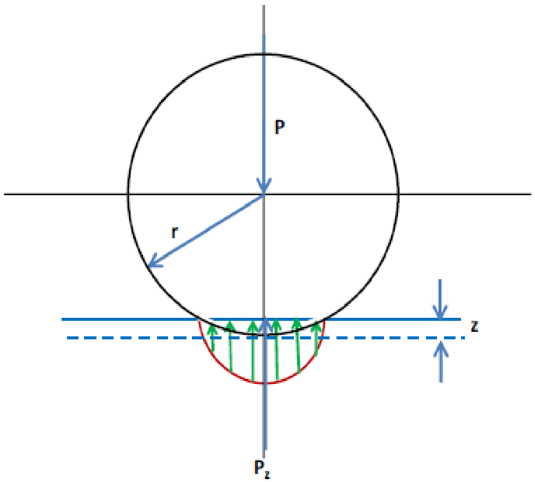
$\sum F_t$ = total tractive effort $[Nm]$

$\sum F_{resistance}$ = total resistance $[Nm]$

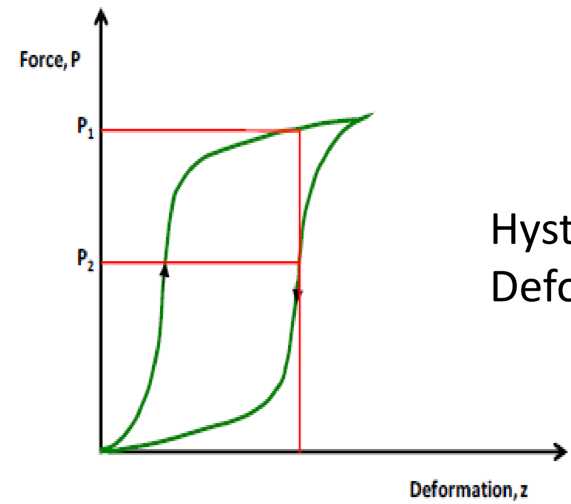
M = total mass of the vehicle $[kg]$

δ = mass factor for converting the rotational inertias of rotating components into translational mass

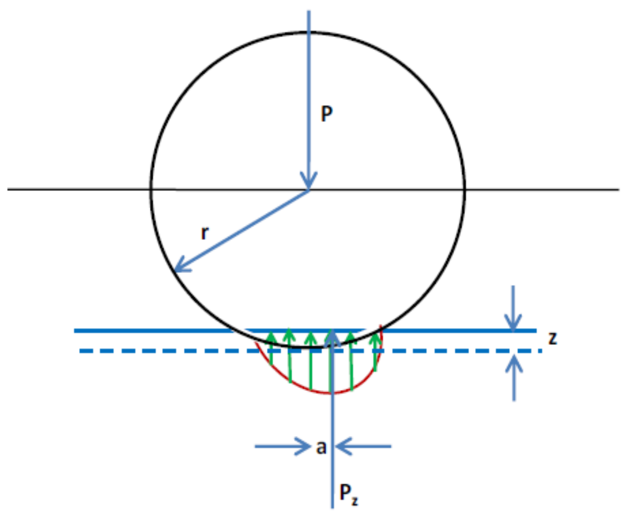
Rolling Resistance



Stand-still



Hysteresis Deformation



Loading & Unloading

- The moment produced by forward shift of the resultant ground reaction force is called rolling resistance moment

$$T_r = Pa = Mga$$

where

T_r = rolling resistance $[Nm]$

P = Normal load acting on the centre of the rolling wheel $[N]$

M = mass of the vehicle $[kg]$

g = acceleration constant $[m/s^2]$

a = deformation of the tyre $[m]$

- To keeps the wheel rolling, a force $\mathbf{F_r}$, acting on the center of the wheel is required to balance this rolling resistant moment.

$$F_r = \frac{T_r}{r_{dyn}} = \frac{Pa}{r_{dyn}} = Pf_r$$

where

T_r = rolling resistance $[Nm]$

P = Normal load acting on the centre of the rolling wheel $[N]$

r_{dyn} = dynamic radius of the tyre $[m]$

f_r = rolling resistance coefficient

- Or equivalently expressing it as a horizontal force acting opposite to movement of wheel.

$$F_r = Pf_r$$

where

P = Normal load acting on the centre of the rolling wheel $[N]$

f_r = rolling resistance coefficient

- Suppose we consider the vehicle is going Uphill.

$$F_r = Pf_r \cos(\alpha) = Mgf_r \cos(\alpha)$$

where

P = Normal load acting on the centre of the rolling wheel $[N]$

f_r = rolling resistance coefficient

α = road angle $[radians]$

F_r are given in table (1).

The rolling resistance coefficient, $\mathbf{F_r}$, is a function of:
a)Tire material ,b)Tire structure ,c)Tire temperature
d)Tire inflation pressure etc.

The rolling resistance coefficient of a passenger car on a concrete road may be calculated as:

$$f_r = f_0 + f_s\left(\frac{V}{100}\right)^{2.5}$$

For most common range of inflation pressure, the following equation can be used for a passenger car on a concrete road

$$f_r = 0.01\left(1+\frac{V}{160}\right)$$

where

V = vehicle speed $[km/h]$

Aerodynamic Drag

1)Shape drag

2)Skin effect

$$F_w = \frac{1}{2}\rho A_f C_D V^2$$

where

ρ = density of air $[kg/m^3]$

A_f = vehicle frontal area $[m^2]$

V = vehicle speed $[m/s]$

C_D = drag coefficient

C_D and A_f in table(2)

Grading Resistance

- When a vehicle goes up or down a slope, its weight produces a component of force that is always directed downwards. This force component opposes the forward motion, i.e. the grade climbing.

$$F_g = Mg\sin(\alpha)$$

where

M = mass of vehicle $[kg]$

g = acceleration constant $[m/s^2]$

α = road angle $[radians]$

- In some literature, the tire rolling resistance and the grading resistance taken together and is called **road resistance.** The road resistance is expressed as

$$F_{rd} = F_f + F_g = Mg\left(f_r \cos(\alpha) + \sin(\alpha)\right)$$

Acceleration resistance

$$F_a = \left(M + \frac{\sum J_{rot}}{r_{dyn}^2} \right) \frac{dV}{dt}$$

where

M = mass of vehicle $[kg]$

J_{rot} = intertia of rotational components $[kg \times m^2]$

V = speed of the vehicle $[km / h]$

$r_{dyn} = dynamic\ radius\ of\ the\ tyre\ [m]$

- Or equivalently

$$F_a = \lambda M \frac{dV}{dt}$$

where

λ = rotational inertia constant

M = mass of the vehicle $[kg]$

V = speed of the vehicle $[m/s]$

- Total driving resistance

$$F_{resistance} = F_r + F_w + F_g + F_a$$

- Substituting with the expressions

$$F_{resistance} = Mgf_r \cos(\alpha) + \frac{1}{2}\rho A_f C_D V^2 + Mg\sin(\alpha) + \lambda M \frac{dV}{dt}$$

- Power required (**P_{req}**)

$$P_{req} = F_{resistance} V$$

Dynamic equation

$$M\frac{dV}{dt}=\left(F_{tf}+F_{tr}\right)-\left(F_{rf}+F_{rr}+F_{w}+F_{g}+F_{a}\right)$$

Adhesion, Dynamic wheel radius and slip

- Tractive effort of a vehicle > maximum tractive effort limit
- Results in “spinning of wheels”
- The slip between the tires and the surface can be described as:

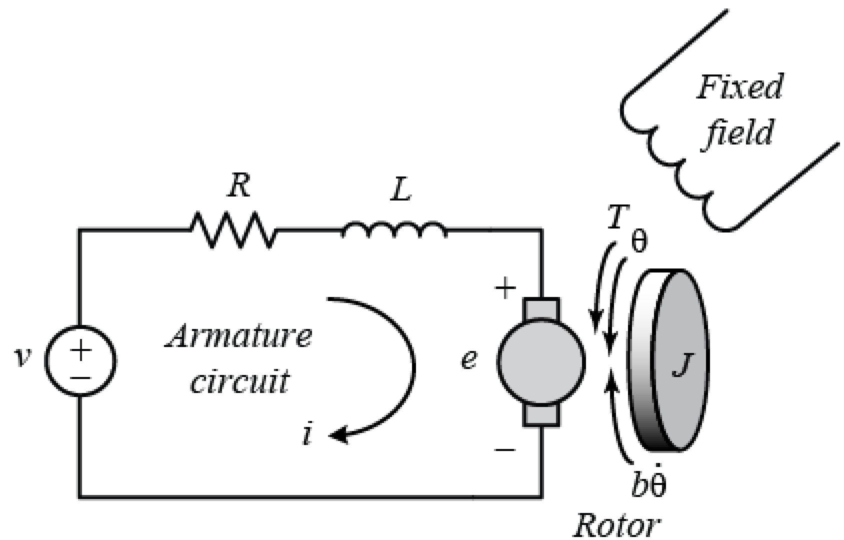
$$drive\ slip\ S_T = \frac{\omega_R r_{dyn} - V}{\omega_R r_{dyn}}$$

- The dynamic wheel radius ($\mathbf{r}_{\mathbf{dyn}}$) is calculated from the distance travelled per revolution of the wheel, rolling without slip.

- Dynamic wheel radius of common tire sizes in table(4).

Mathematical Modeling of Electric Motor

Basic Diagram



Equations Involved

$$T = K_t i$$

$$e = K_e \dot{\theta}$$

$$J\ddot{\theta} + b\dot{\theta} = Ki$$

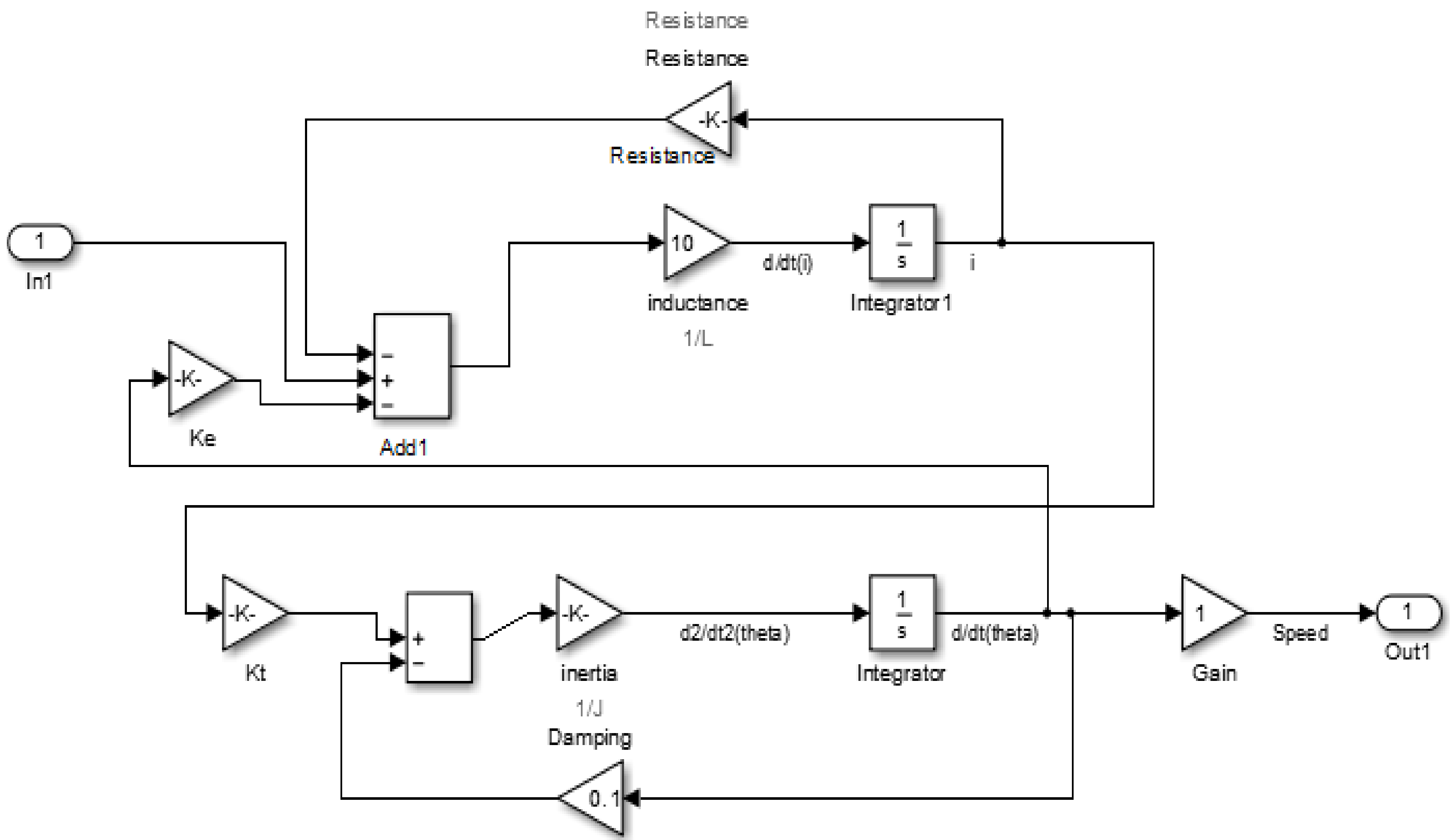
$$L\frac{di}{dt} + Ri = V - K\dot{\theta}$$

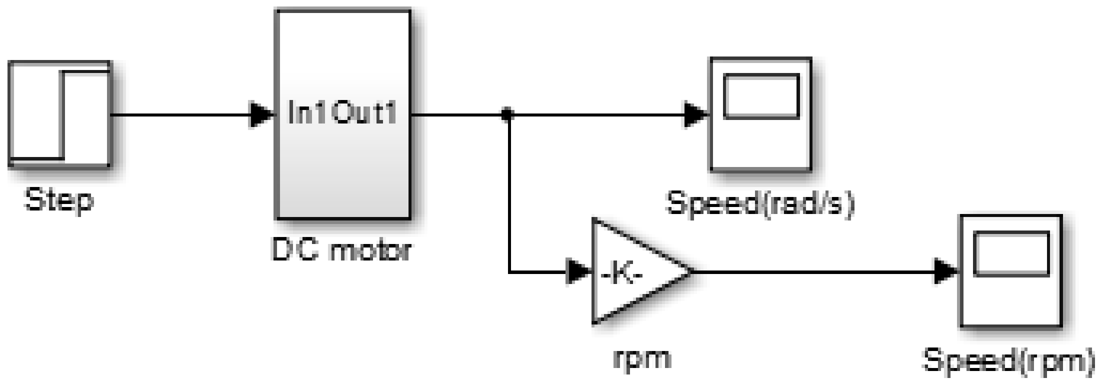
Laplace Transform & Transfer Function

$$s(Js+b)\Theta(s) = KI(s)$$

$$(Ls+R)I(s) = V(s) - Ks\Theta(s)$$

$$P(s) = \frac{\dot{\Theta}(s)}{V(s)} = \frac{K}{(Js+b)(Ls+R)+K^2} \qquad \left[\frac{rad/sec}{V}\right]$$


Resistance
Resistance
-K-
Resistance
1
In1
10
d/dt(i)
1/s
i
inductance
Integrator1
1/L
-K-
Ke
Add1
-K-
Kt
-K-
inertia
d2/dt2(theta)
1/s
Integrator
d/dt(theta)
1
Gain
Speed
1
Out1
1/J
Damping
0.1



In1Out1
Step
DC motor
-K-
rpm
Speed(rad/s)
Speed(rpm)

One dimensional modeling of an internal combustion engine.

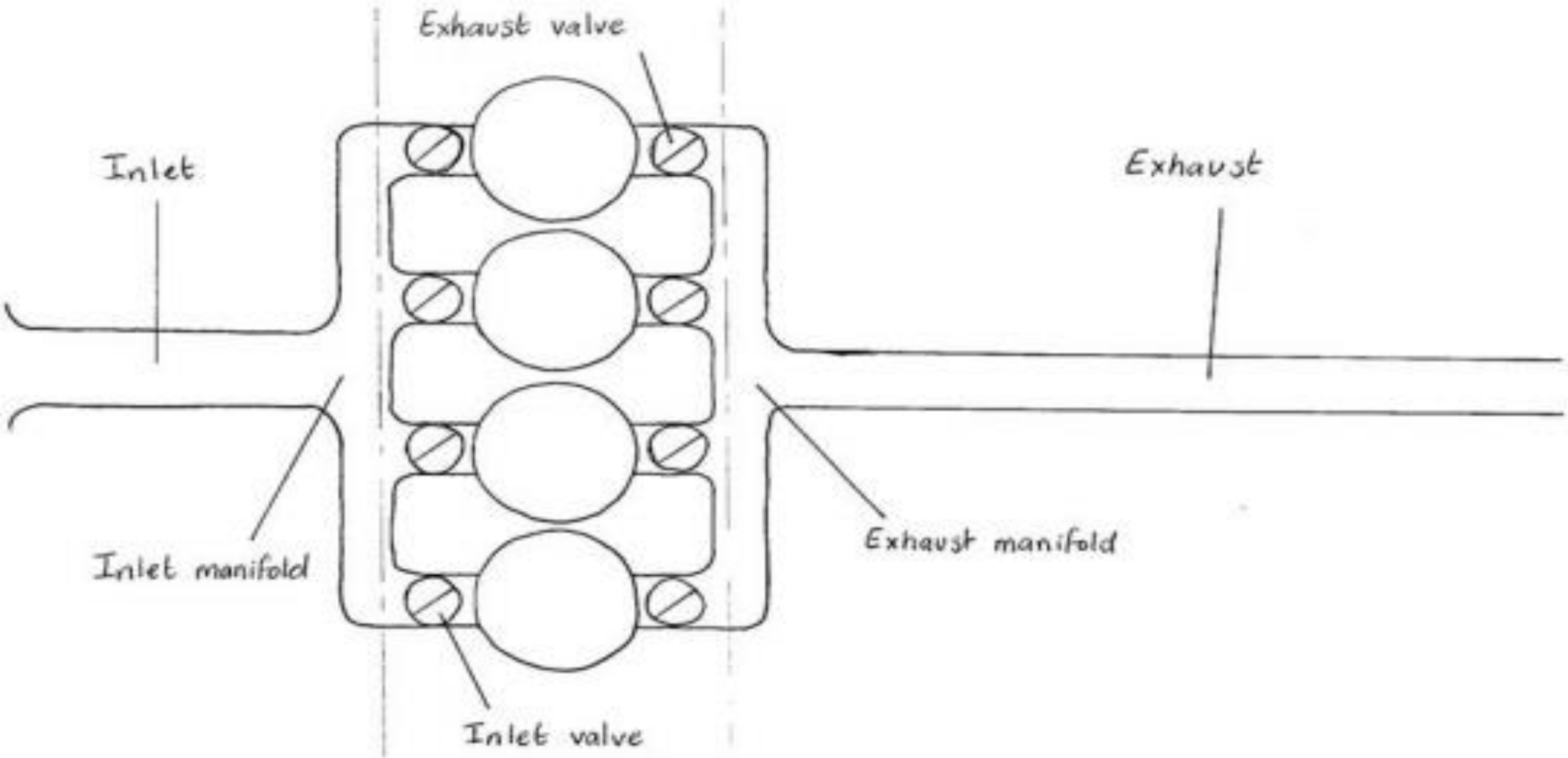
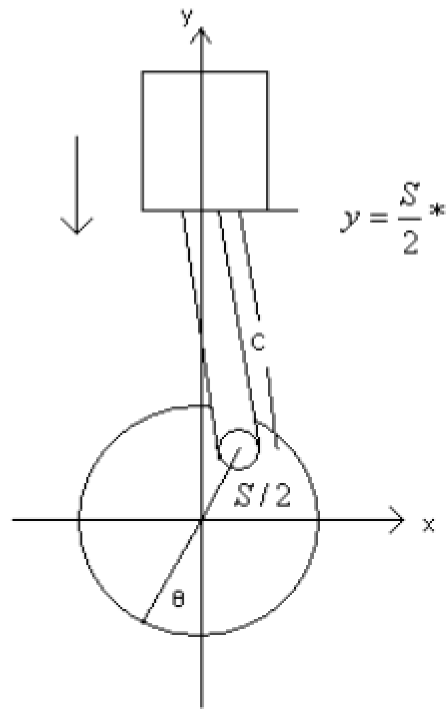


Fig 1. Model of the engine

Sub-models

- 1. Piston Velocity



$$y = \frac{S}{2} * \cos\theta + \left(c^2 - \frac{S}{2} * \sin\theta\right)^2$$

Fig. 2 Side view of piston

$$\dot{y}(\theta) = \frac{S}{2} * \sin\theta \left[-1 - \frac{S * \cos\theta}{2 * \sqrt{L_c^{\ 2} - \frac{S^2 * \sin^2\theta}{4}}} \right] \dot{\theta}$$

$$v_{p\_\max} \Rightarrow \theta = \frac{\pi}{2} \Rightarrow \left| v_{p\_\max} \right| = \frac{S}{2} * \dot{\theta}$$

$$\dot{\theta} = \frac{rpm * \pi}{30} \Rightarrow v_{p\_\max} = \frac{S * \pi * rpm}{60}$$

Incompressible flow

$$u_{ip\_\max} * A_{ip} = v_{p\_\max} * A_p$$

$$u_{ip\_\max} = v_{p\_\max} * \left(\frac{B}{d_{ip}}\right)^2$$

$$rpm = \frac{M * a * 60}{S * \pi} * \left(\frac{d_{ip}}{B}\right)^2$$

$$\text{rpm} = 752$$

Compressible flow

$$P * V = m * R * T$$

$$V_c = \frac{\pi * B^2 * S}{4}$$

$$m_{in} = \frac{P_{atm} * \pi * B^2 * S}{4 * R * T_{atm}} = 5.99 * 10^{-4}\, kg$$

$$t_{open} = (180^0) = \left(\frac{rpm}{60}\right)^{-1} * 0.5 = \frac{30}{rpm} \sec$$

$$\dot{m}_{in} = \frac{5.99 * 10^{-4} * rpm}{30} = 2.00 * 10^{-5} * rpm \;\; kg * s^{-1}$$

$$\dot{m}_{in} = \rho * u_{ip} * A_{ip} = \rho * M * a * A_{ip} = \rho * M * \sqrt{\gamma * R * T} * A_{ip} =$$

$$= \frac{\rho}{\rho_0} * \rho_0 * M * \sqrt{\gamma * R} * \sqrt{\frac{T}{T_0}} * \sqrt{T_0} * A_{ip}$$

$$\because \dot{m}_{in} = \rho_0 * \sqrt{\gamma * R * T_0} * A_{ip} * \frac{\rho}{\rho_0} * \left(\frac{T}{T_0}\right)^{\frac{1}{2}} * M$$

$$\frac{\rho}{\rho_0} = \left[1 + \frac{1}{2}(\gamma - 1)M^2\right]^{\frac{-1}{\gamma-1}} \ \& \ \frac{T}{T_0} = \left[1 + \frac{1}{2}(\gamma - 1)M^2\right]^{-1}$$

$$\dot{m}_{in} = \rho_0 * \sqrt{\gamma * R * T_0} * A_{ip} * \left[1 + \frac{1}{2}(\gamma - 1)M^2\right]^{\frac{-1}{\gamma-1} - \frac{1}{2}}$$

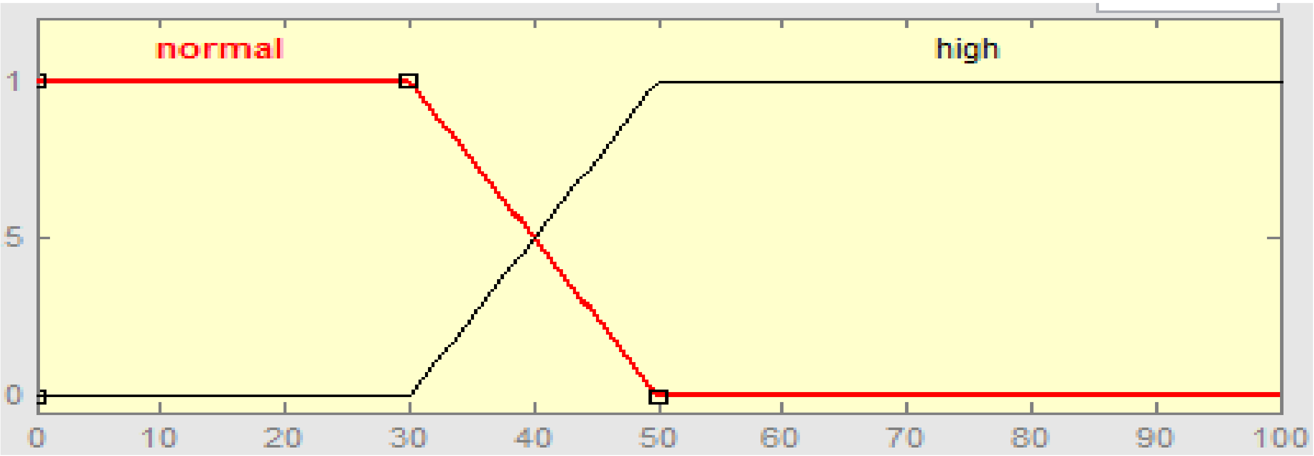
$$8.484 * 10^{-5} * rpm = M * \left[1 + 0.2M^2\right]^{-3}$$

Exhaust flow

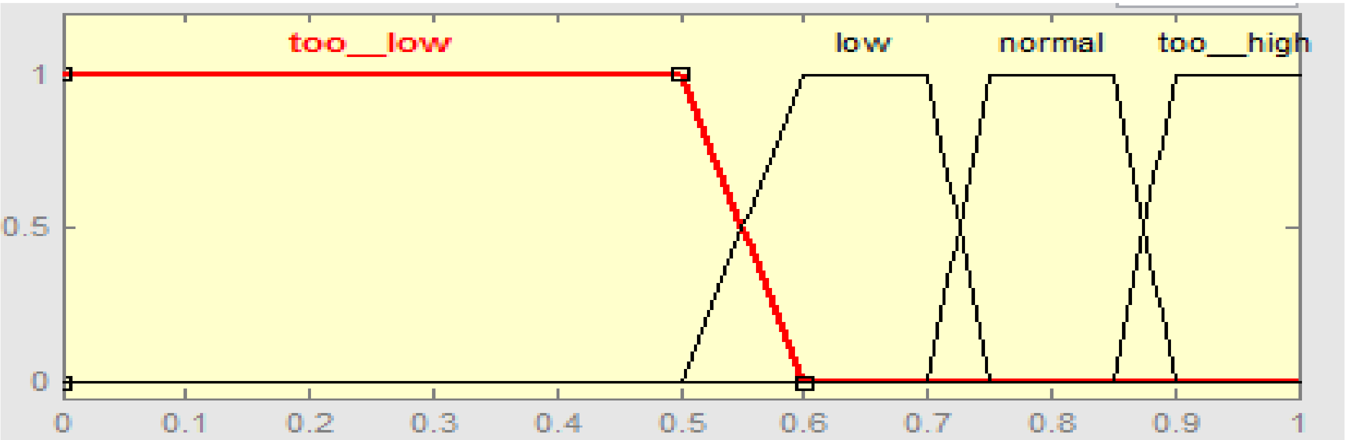
$$1.1701 * 10^{-5} * rpm = M * \left[1 + 0.2M^2\right]^{-3}$$

Fuzzy Logic Controller

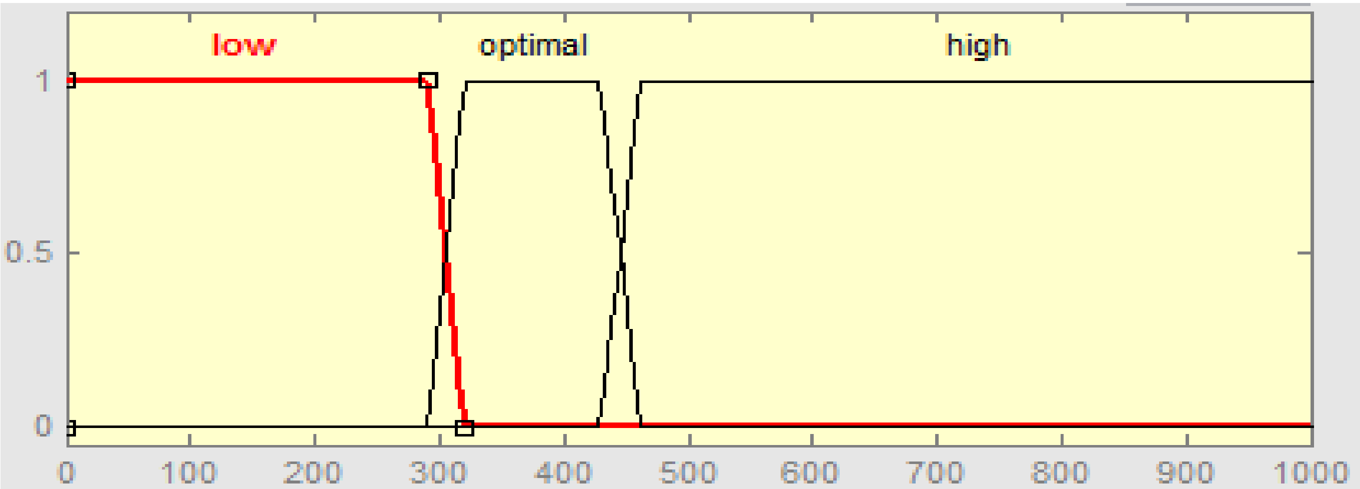
- Inputs:-



1)Driver Power Command (kW)



2)State of Charge (SOC)



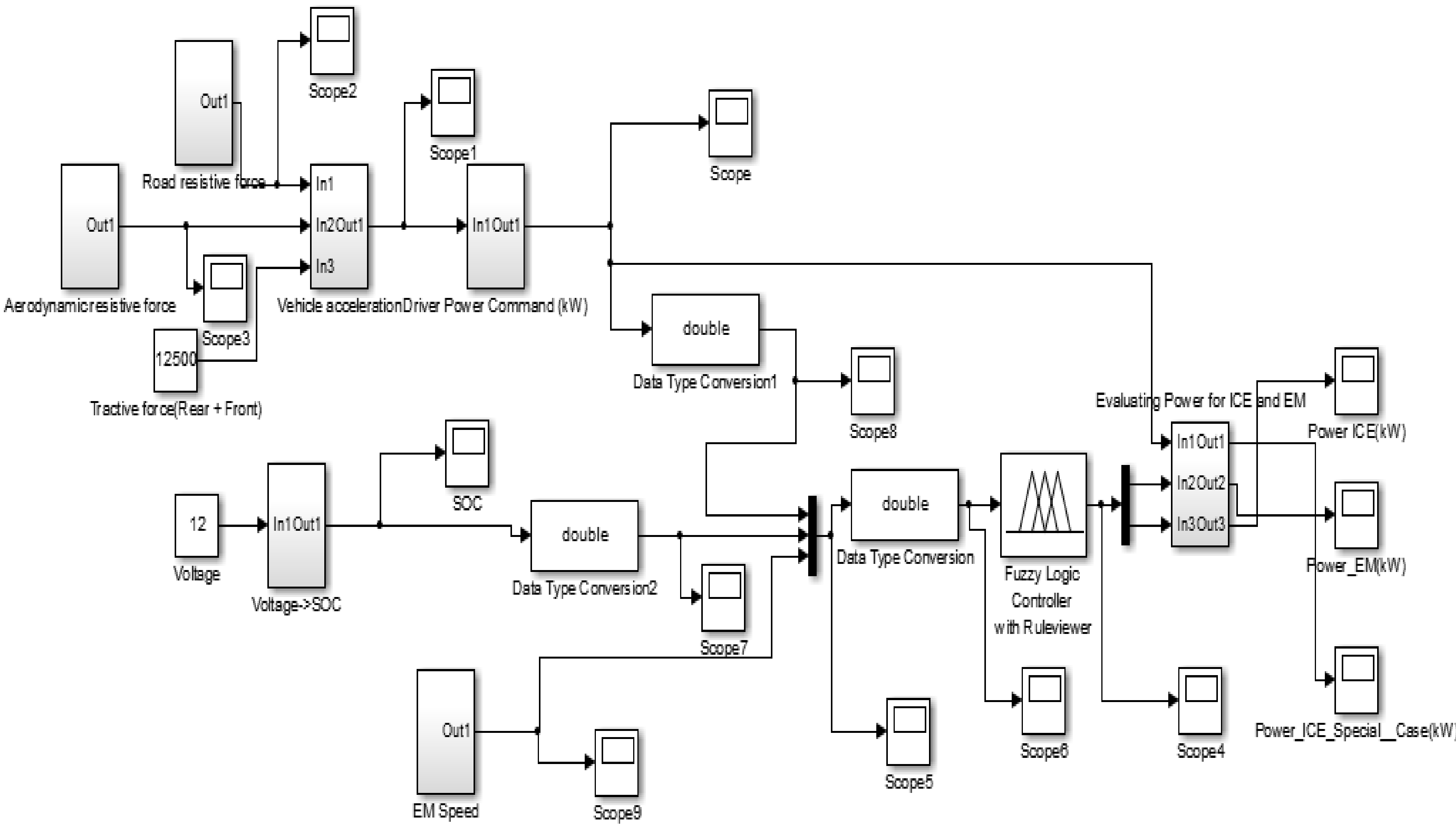
3)EM Speed

Rule Base

RULE BASE OF THE FUZZY LOGIC CONTROLLER

1	**If** SOC is too high **then** P_{gen} is 0 kW
2	**If** SOC is normal **and** P_{driver} is normal **and** ω_{EM} is optimal **then** P_{gen} is 10 kW
3	**If** SOC is normal **and** ω_{EM} is **not** optimal **then** P_{gen} is 0 kW
4	**If** SOC is low **and** P_{driver} is normal **and** ω_{EM} is low **then** P_{gen} is 5 kW
5	**If** SOC is low **and** P_{driver} is normal **and** ω_{EM} is **not** low **then** P_{gen} is 15 kW
6	**If** SOC is too low **then** P_{gen} is $P_{gen,max}$
7	**If** SOC is too low **then** scale factor is 0
8	**If** SOC is **not** too low **and** P_{driver} is high **then** P_{gen} is 0 kW
9	**If** SOC is **not** too low **then** scale factor is 1

Simulink Model



Example

- Inputs:-
  1) Tractive Force (rear + front) = 12500W
- 2) Voltage (Battery)=12V

- Outputs:-
  1) Power _ ICE = 20.2417 kW
- 2) Power _ EM = -7.5 kW