AUBURN UNIVERSITY

Electric Vehicles

ELEC 5970/6970/6970-D01

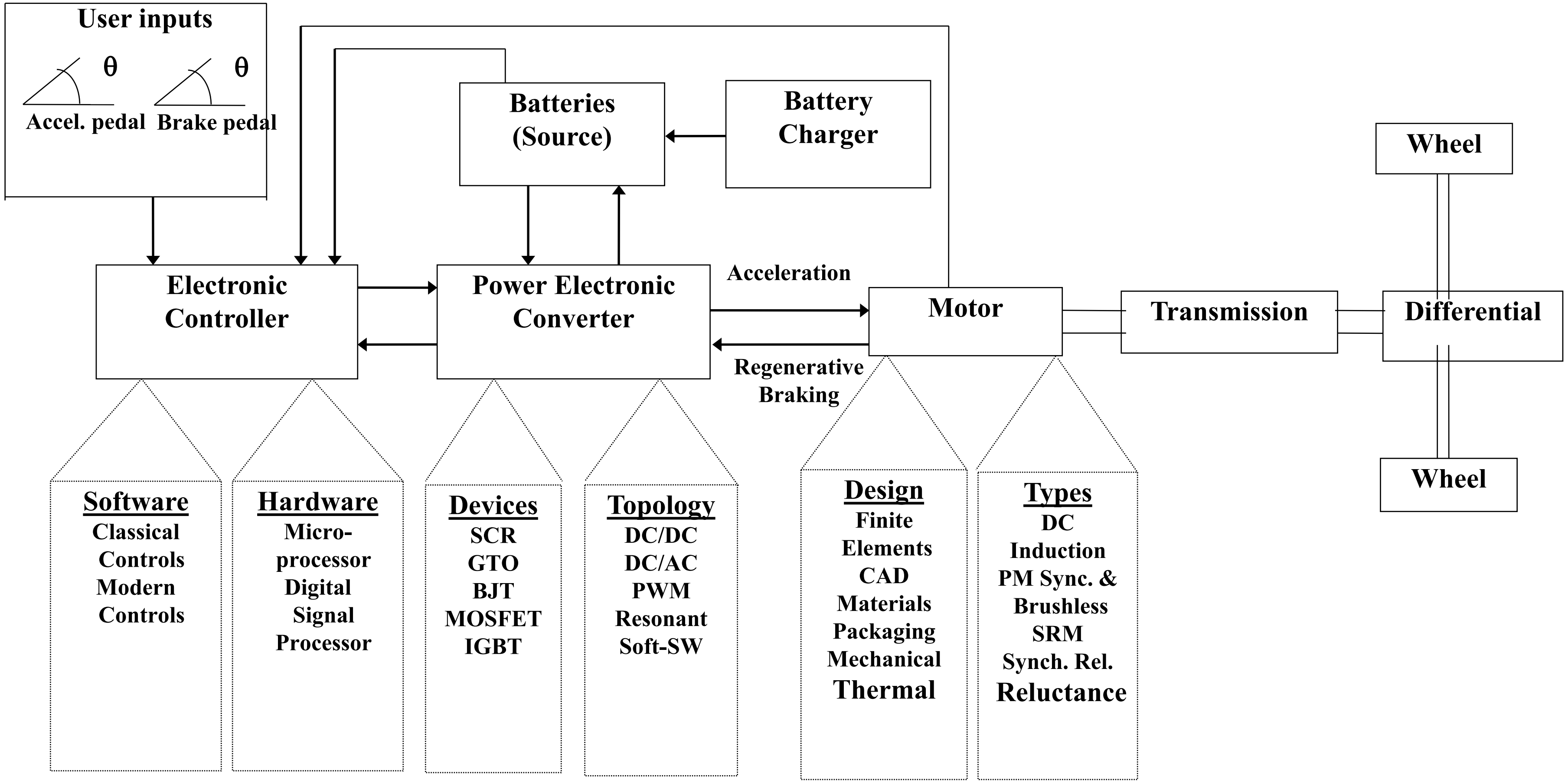
Alternative Vehicle Architectures

References:

- Iqbal Husain, ”Electric and Hybrid Vehicles, Design Fundamentals,” Third Edition, March 2021, CRC Press, Taylor & Francis Group, ISBN: 978-0429-49092-7

Alternative Vehicle Architectures

EV Transmission Path



Electric and Hybrid Vehicles

- Electric Vehicles
  - The energy source is portable and electrochemical in nature.
  - Tractive effort is supplied only by an electric motor.
    - Battery Electric Vehicle
    - Fuel Cell Electric Vehicle
- Hybrid Vehicles
  - A vehicle in which at least one of the energy sources, stores or converters can deliver electric energy.
  - The propulsion energy during specified operational missions, is available from two or more kinds or types of energy stores, sources or converters, of which at least one store or converter must be on board.
    - Charge Sustaining HEV
    - Plug-in HEV (PHEV) or Charge Depleting HEV

Hybrid Electric Vehicles Definitions

Hybrid Classifications (Degree of Hybridization):

- Micro Hybrids – 3 kW to 5 kW power levels (energy capacity 1-3 kWh)
  - Fuel economy of 5% to 10%
- Mild Hybrids – 10 kW to 15 kW power levels (energy capacity 1-3 kWh)
  - Fuel economy of 7% to 15%
  - Uses a low power S/A typically termed as ISG
- Strong/Power Hybrids - >20 kW power levels
  - Fuel economy >30%
  - Limited electric only range (~7km)
  - Downsized engine, smaller transmission compared to an ICEV
  - Higher cost and complexity
- Energy Hybrid - 70kW to 100 kW
  - Higher energy storage (energy capacity 15-20 kWh)
  - Longer zero emission range (e.g., zev-50 = zero emission range 50 miles)

Hybrid Electric Vehicles Definitions

- Hybrid Classifications (Charging Capability)
  - Charge Sustaining
    - Never needs to be plugged in
  - Charge Depleting
    - Plug-in Hybrid

Hybrid Electric Vehicles Definitions

- Hybrid Powertrain Architectures
  - Series
  - Parallel
    - Through-the-road-parallel
    - 2×2 Wheel Drive
  - Pre-transmission
  - Post-transmission
    - Motor rotates at vehicle speed
  - Series-Parallel Split

Series HEV

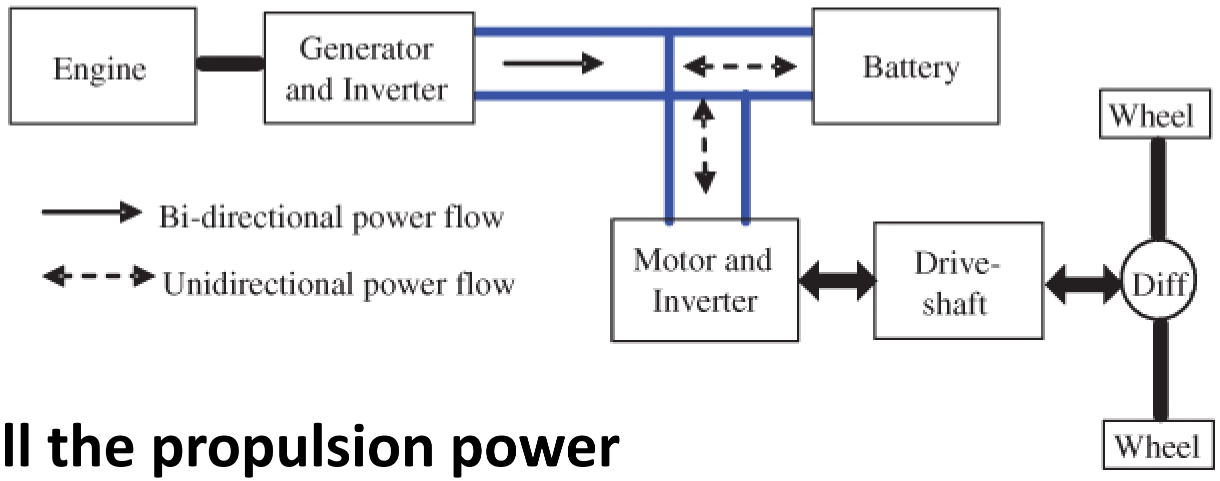


FIGURE 3.2 Series HEV powertrain.

The electric motor provides all the propulsion power

- Advantages:
  - Flexibility of location of engine-generator (e-g) set
  - Simplicity of drivetrain
  - Suitable for short trips
- Disadvantages
  - Needs 3 propulsion components (ICE, Generator and Motor)
  - Motors must be designed for maximum sustained power, *P*
  - Most of the time vehicle operates below P_{max}
  - All 3 drivetrain components need to be sized for long distance-sustained, high-speed driving

Series Hybrids

- **Possible designs**
  - ICE rated for full Traction power; Electric Drive with modest energy storage for dynamic events, such as launch, acc, braking etc.
  - Series with electrically peaking: ICE rated for average load; Electric Drive for dynamic events plus adequate energy storage to sustain dynamic loads
  - Larger vehicles, such as locomotives, buses are series type. The vehicles have well-defined usage, acceleration requirements not so stringent, and the added mass for hybridization not significant compared to vehicle mass.

Parallel HEV

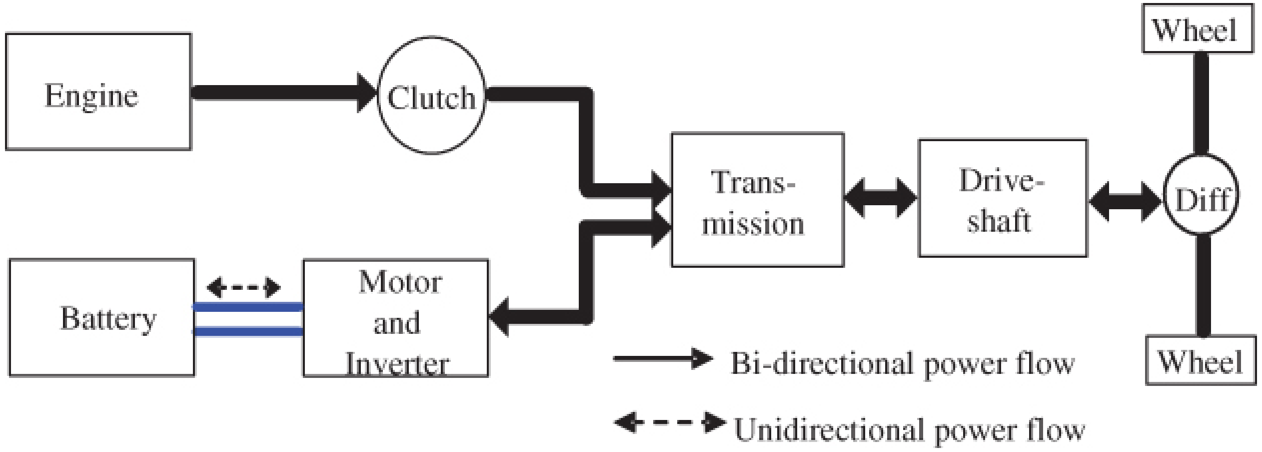
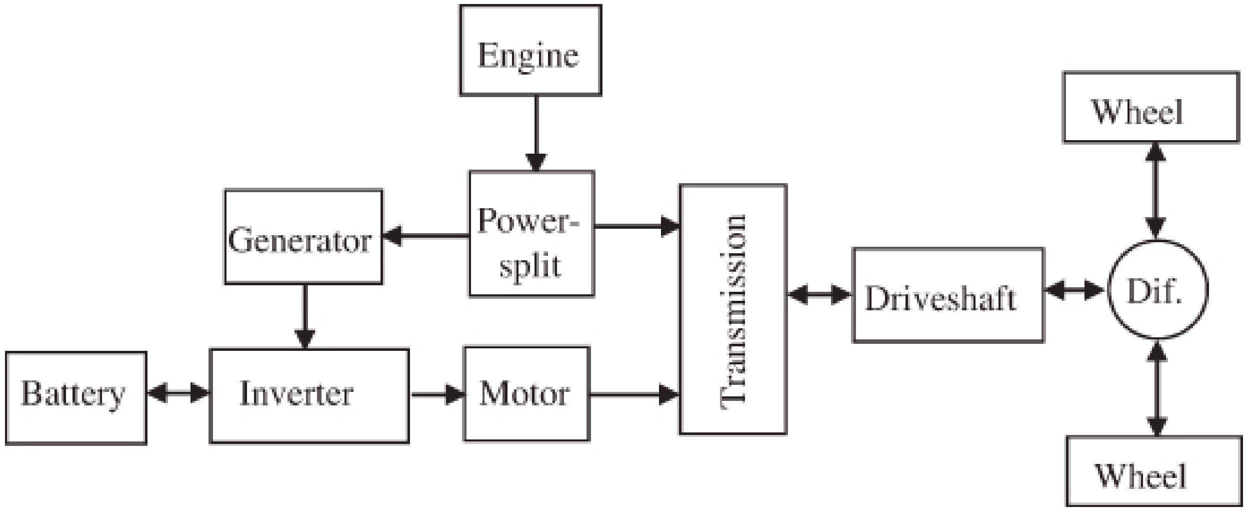


FIGURE 3.3 Parallel HEV powertrain.

Both the ICE and the electric motor are connected to the driveshaft

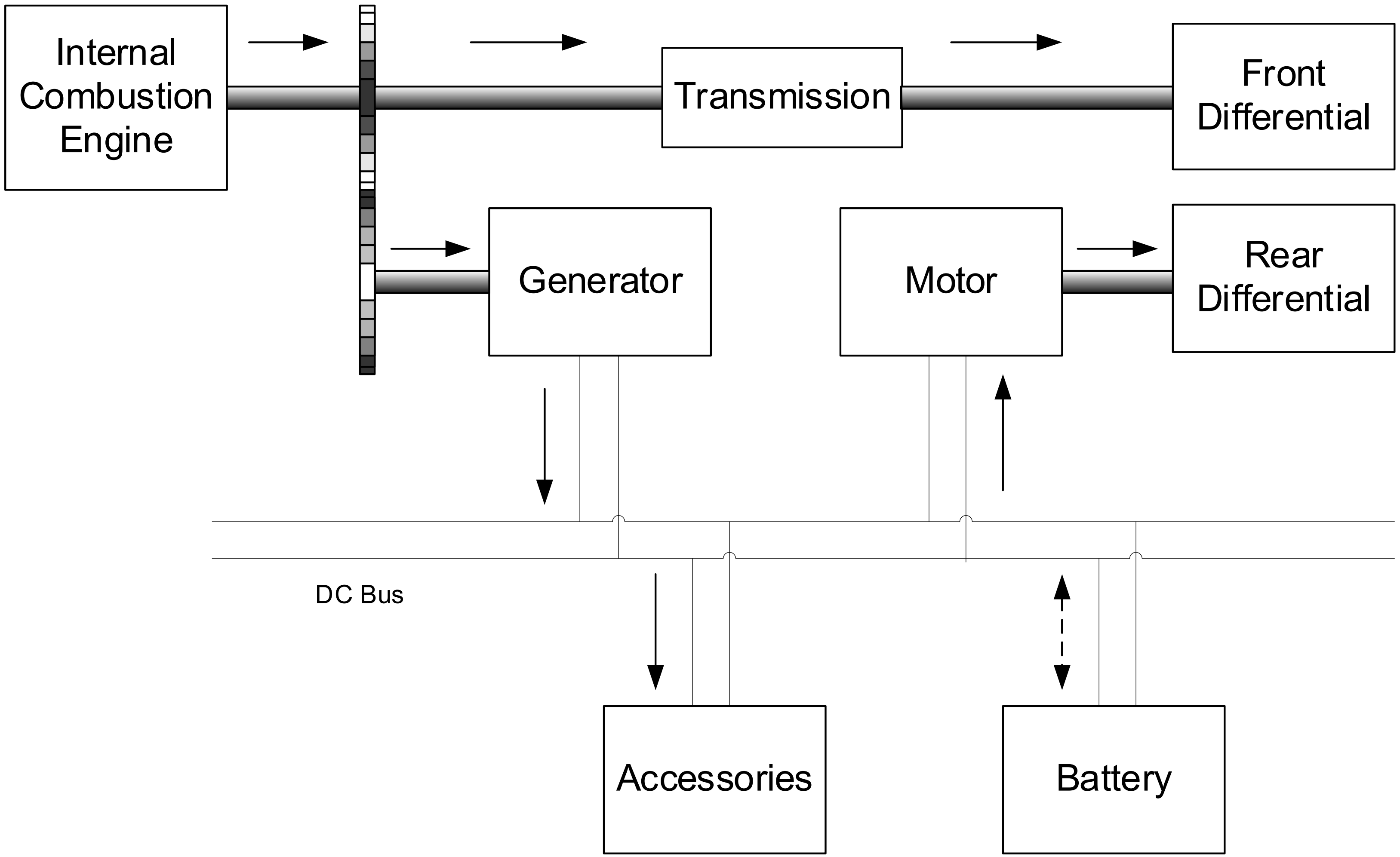
- ❑Advantages
  - Needs only 2 propulsion components (ICE, motor or Generator)
  - Smaller engine or motor can produce the same performance
- ❑Disadvantages
  - Control complexity
  - Power blending from the ICE and motor necessitates a complex mechanical device

Series-Parallel Combination HEV



- A small series element + parallel HEV (Ex: Toyota Prius)
- Heat engine is also used to charge the battery
- Electric motor delivers power to the front wheel in parallel with the ICE
- Inverter is bi-directional
- Central control unit regulates the power flow

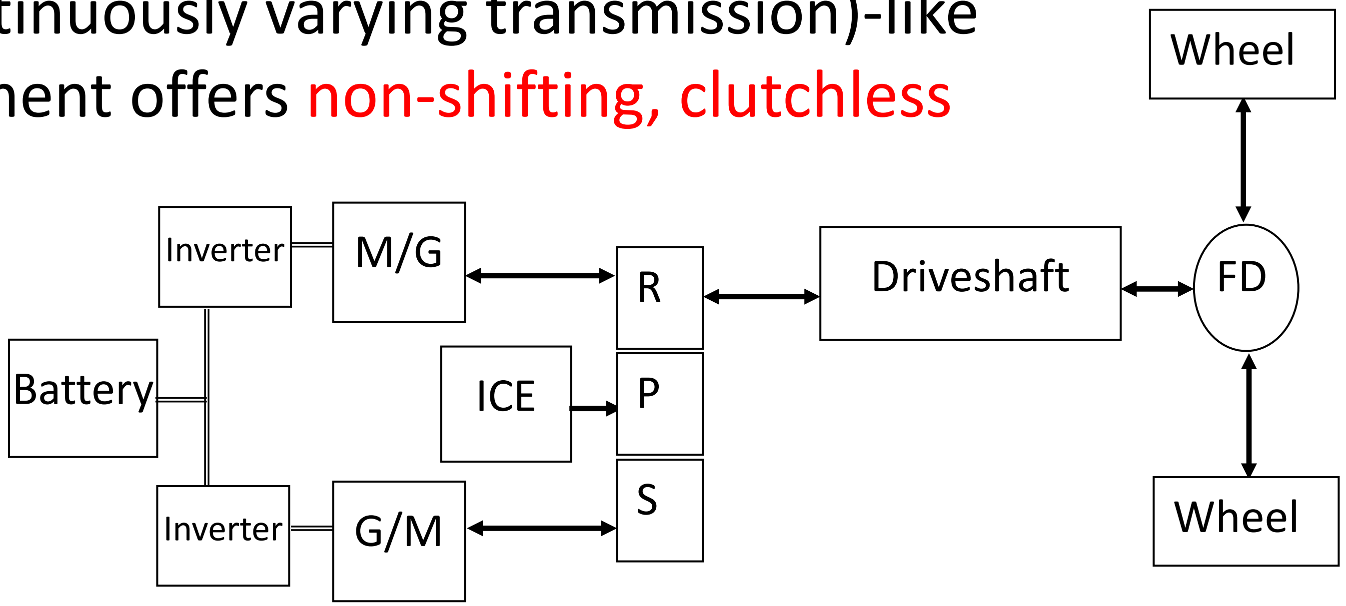
Series-Parallel 2x2 Architecture



Hybrids Based on Transmission Assembly

Power-split Pre-transmission hybrid

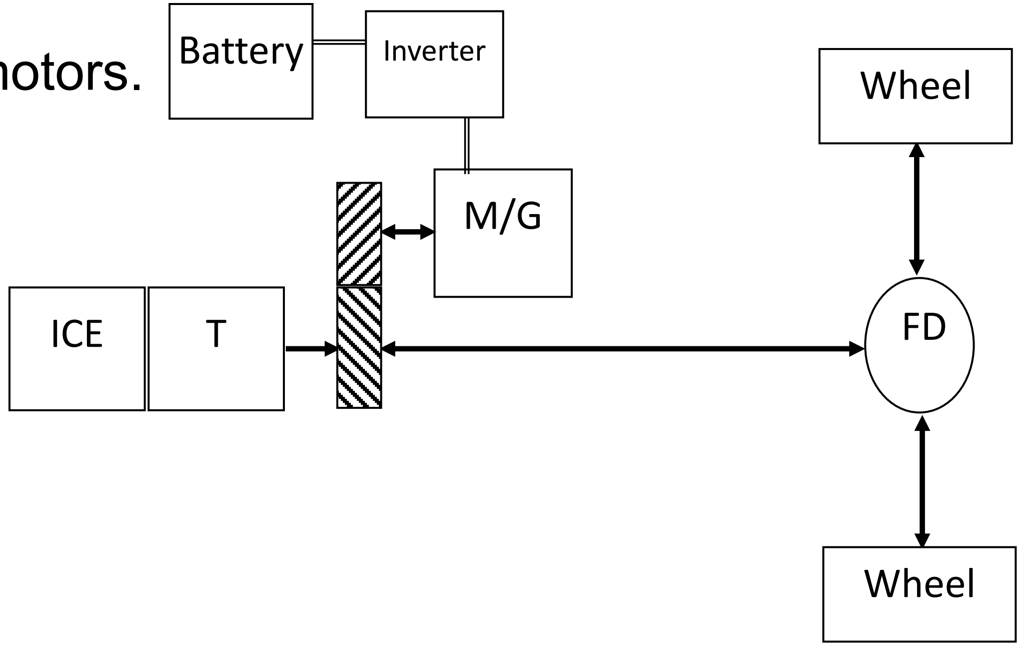
- Electric drive coupled with the ICE before the transmission and drivetrain
- The e-CVT with a planetary gearset connected in pre-transmission configuration is becoming popular in power-split hybrids (like Toyota Prius) which offers CVT (continuously varying transmission)-like performance. This arrangement offers non-shifting, clutchless transmission.



Hybrids Based on Transmission Assembly

Post-transmission hybrids

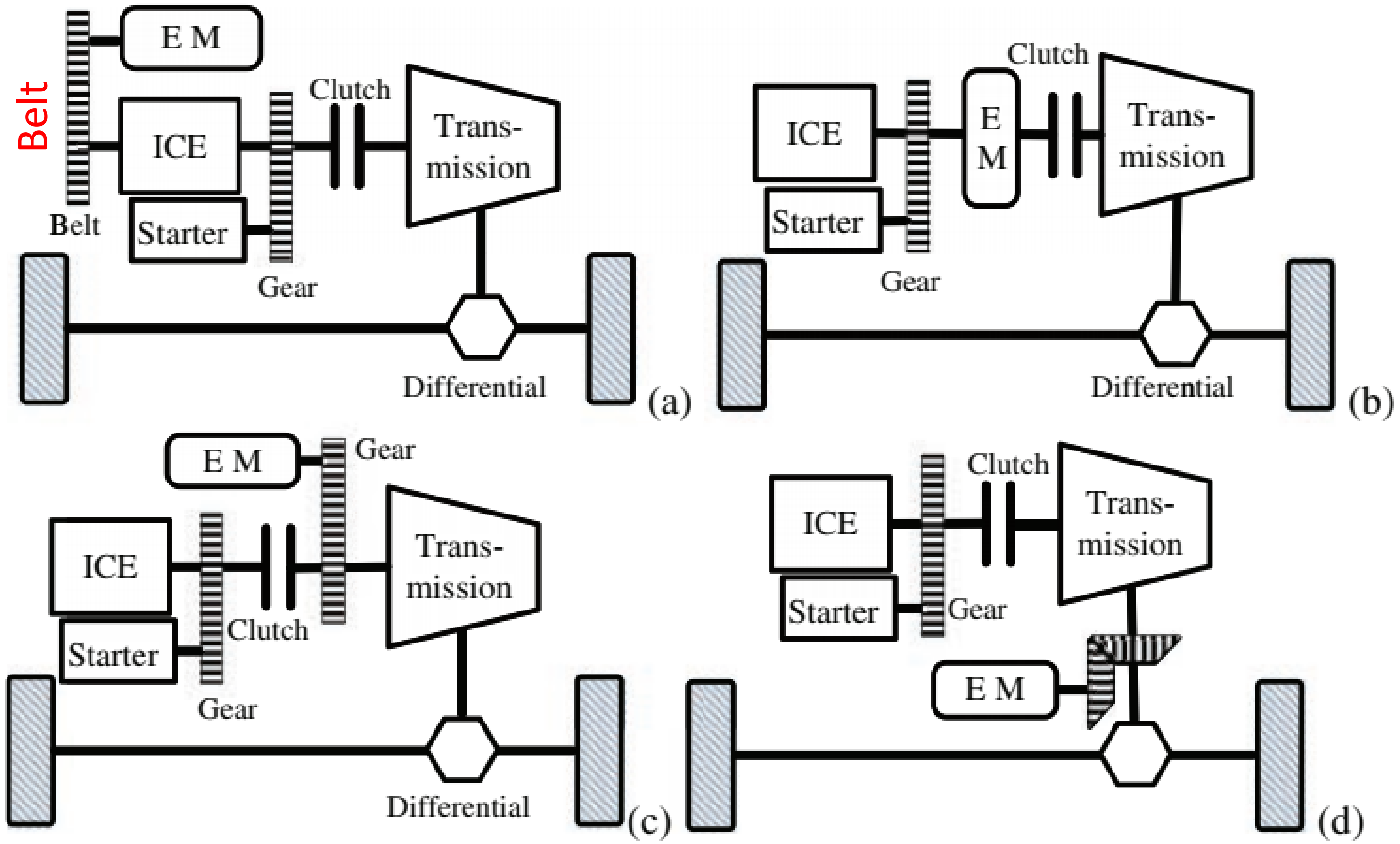
- Electric drive connected at the transmission output shaft, but before the final drive (FD).
- Requires a dedicated device to connect Electric Drive (M/G with driven wheels.
- The Electric Drive must posses >6:1 constant power speed range (CPSR).
- Without a matching transmission, high torque motors are required; this increases the size of the motor.
- Disadvantages: Packaging difficulty, large motor sizes, and impact of continuous spin losses (due to absence of clutch).
- Another example: Wheel motors or Hub motors.



Parallel post-transmission hybrid

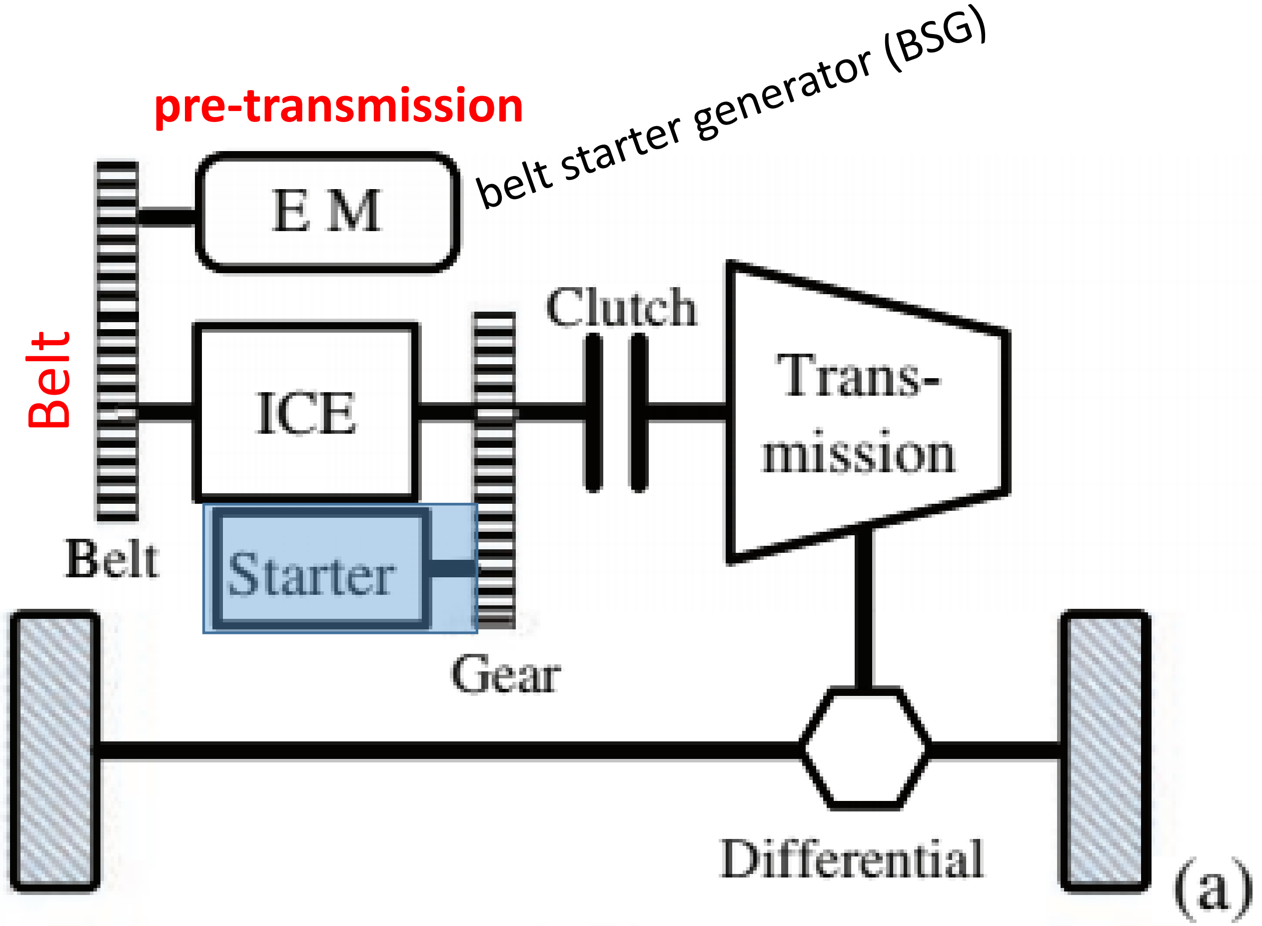
The electric machine within the electric drive is the link between the electrical system and the vehicle system with the pre- and post-transmission arrangements broadly defining the location of the electric drive with respect to the transmission. The pre- and post-transmission arrangements are further classified by the industry as P0, P1, P2, P3 and P4 architectures based on the type of the connection between the electric machine and the powertrain such as belt, integrated or gear mesh. The P0, P1 and P2 architectures are pre-transmission type, while P3 and P4 architectures are the post-transmission type. The four connection type-based architectures are described below with their configurations shown graphically in Figure 3.8.

FIGURE 3.8 HEV P0 to P4 architectures:
(a) P0 architecture with belt-starter generator;
(b) P1 architecture ISG;
(c) P2 architecture and
(d) P3 or P4 architecture.



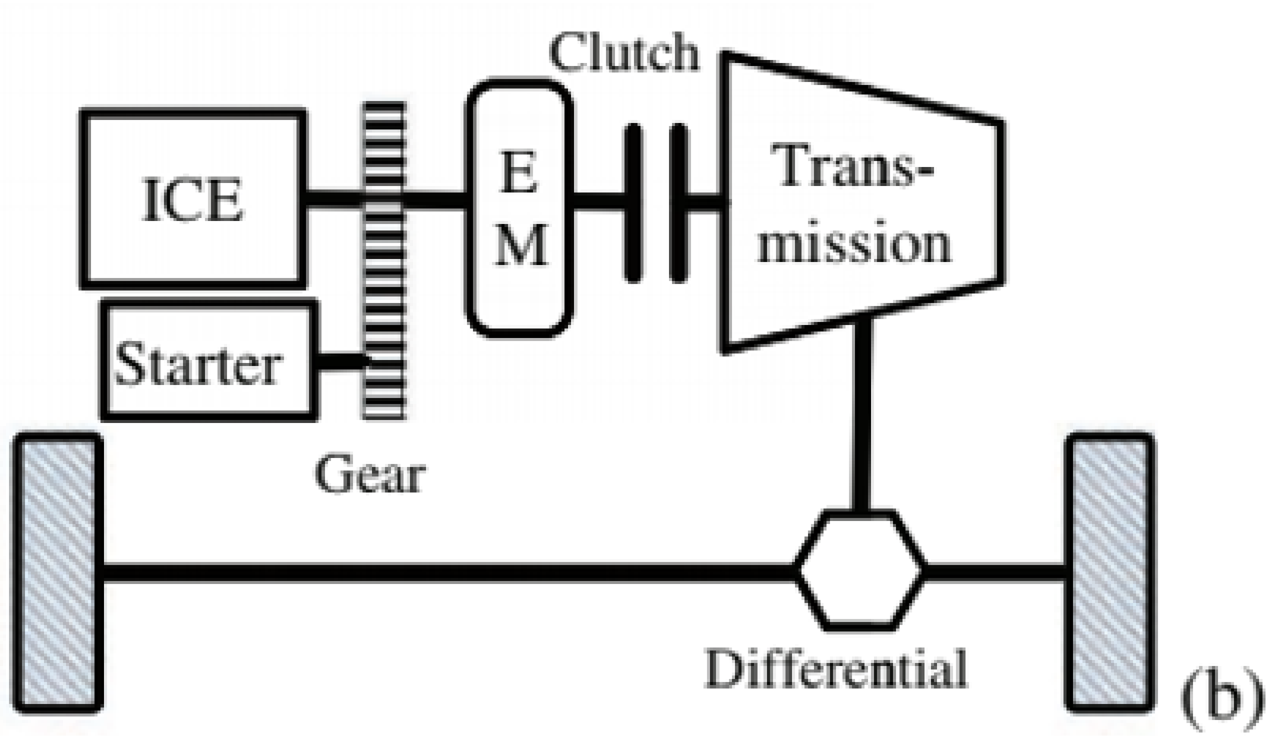
Matlab Resource:
Hybrid and Electric Vehicle Reference Application Projects

P0 – The electric machine is connected with the internal combustion engine through a belt at the front end serving as the replacement of the traditional alternator with higher power rating and regeneration capability. This electric machine is also known as the belt starter generator (BSG).



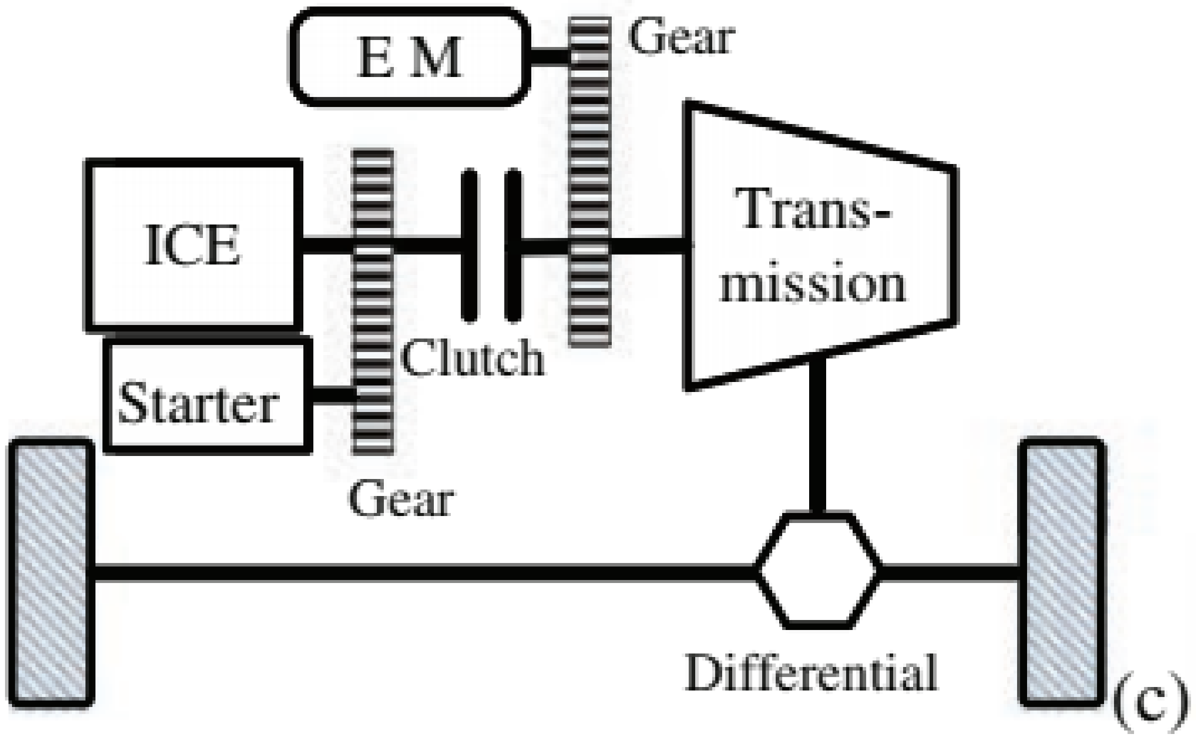
P1 – The electric machine is connected on the crankshaft side of the IC engine through a gearset. This is an integrated starter generator (ISG) arrangement. Neither P0 nor P1 architectures allow the mechanical disconnection of the electric machine from the IC engine.

pre-transmission



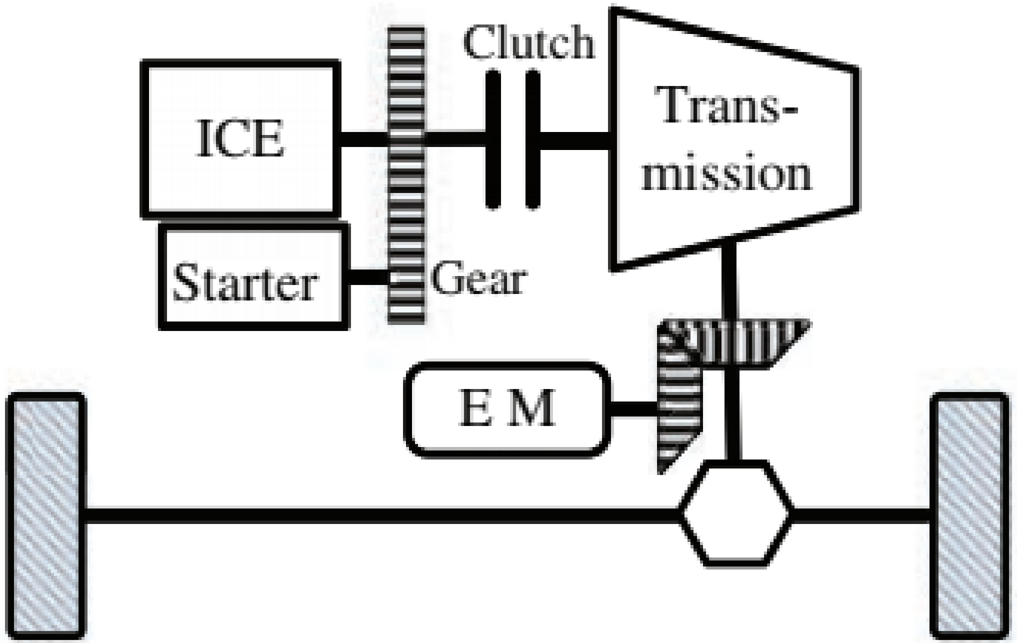
P2 – The electric machine is side-attached to the transmission through a belt or gearset and is ***decoupled from the IC engine*** through a clutch rotating at IC engine speed or geared to rotate at a multiple of IC engine speed. The pre-transmission hybrids with planetary gearset connections are of P1 or P2 type.

pre-transmission



P3 – The P3 is a post-transmission configuration with the electric machine connected with the transmission through a gear mesh. The electric machine is *decoupled from the IC engine* and rotates at a multiple of wheel speed.

P4 – The P4 architecture is also a post-transmission configuration with the electric machine connected through a gear mesh on the rear axle of the vehicle or in the wheels hub. Similar to P3 architecture, the electric machine is decoupled from the IC engine and rotates at a multiple of wheel speed. In P2, P3 or P4 configurations, the electric machine is disconnected from the IC engine through a clutch.

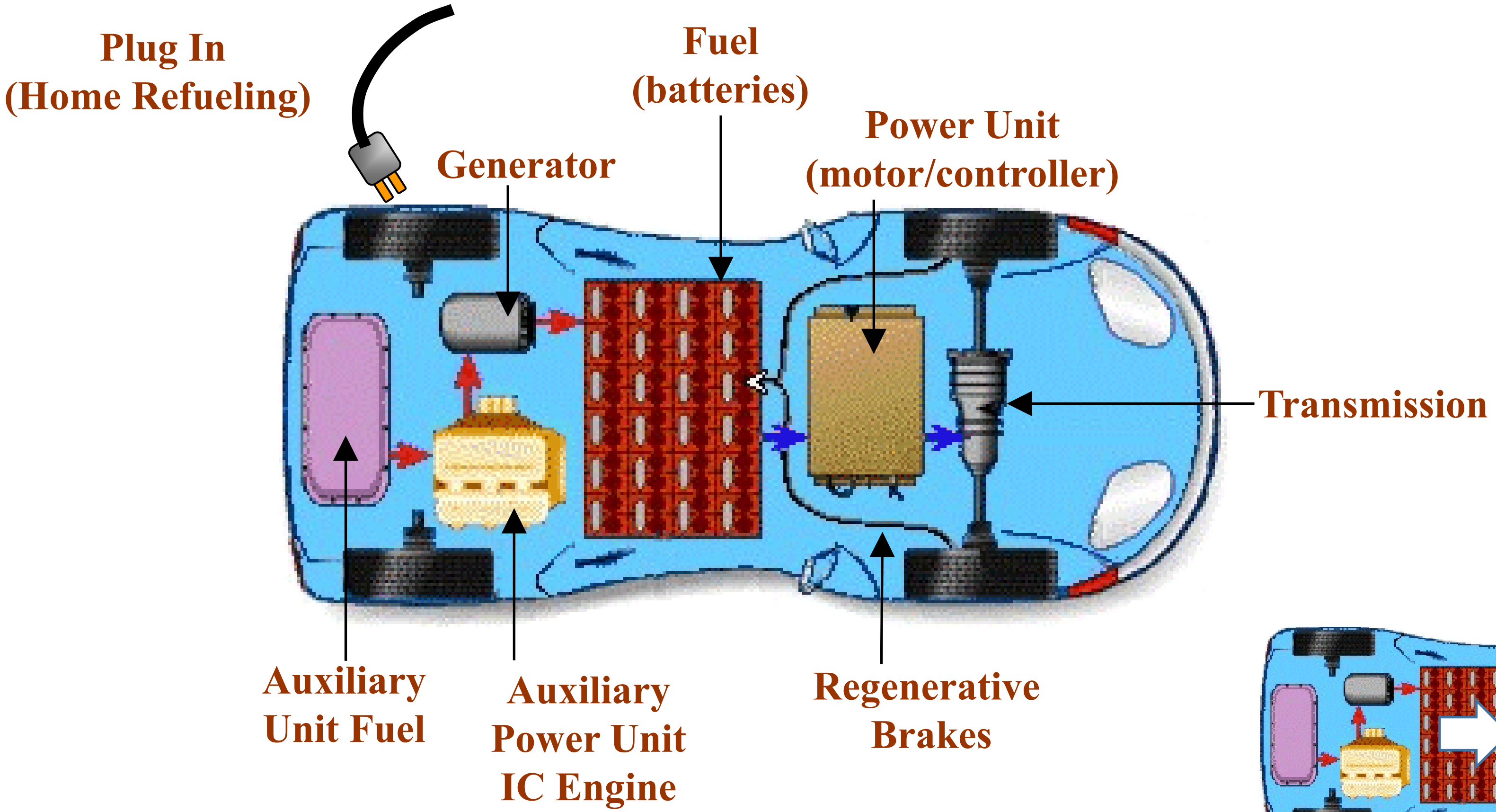


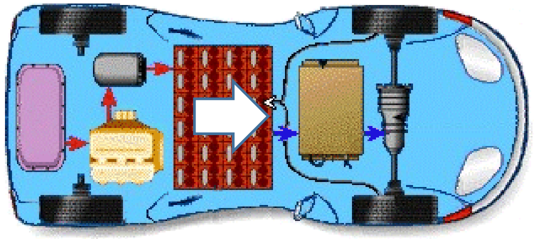
(d)

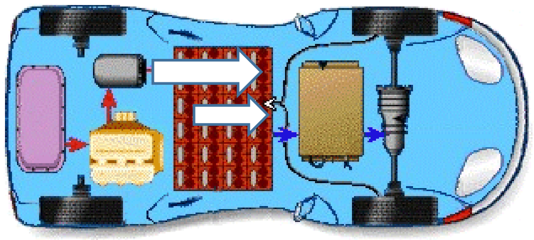
Plug-in HEV and ZEV

- A plug-in hybrid is generally rated based on the zero-emission distance traveled;
- It is designated as PHEV'X' where 'X' is the distance traveled in miles using off-board electrical energy.
- This range of travel where the IC engine is not used is known as the zero-emission vehicle (ZEV) range.
- A PHEV40 is a plug-in hybrid with a useable energy storage capacity equivalent to 40 miles of driving energy on a reference driving cycle.
- The PHEV40 can displace petroleum energy equivalent to 40 miles of driving on the reference cycle with off-board electricity.

Fundamentals of Plug-In HEV







❖ PHEV runs as electric vehicle when the battery charge is high.

❖ Switches to hybrid mode when battery power is low, and when driver requires more power.

Characteristics of PHEV

- PHEV is a hybrid car (HEV) that has additional batteries that can be recharged by plugging them into an electrical outlet.
- Also known as “true hybrids” or “energy hybrids”.
- “Well-to-wheel emissions" of electric vehicles are lower than those from gasoline ICEV.
- Only 20 miles all-electric daily range can have "greenhouse gas" reduction of 20%
- PHEVs will have fuel economy double that of HEV cars.

Series Plug-in Hybrid Vehicle

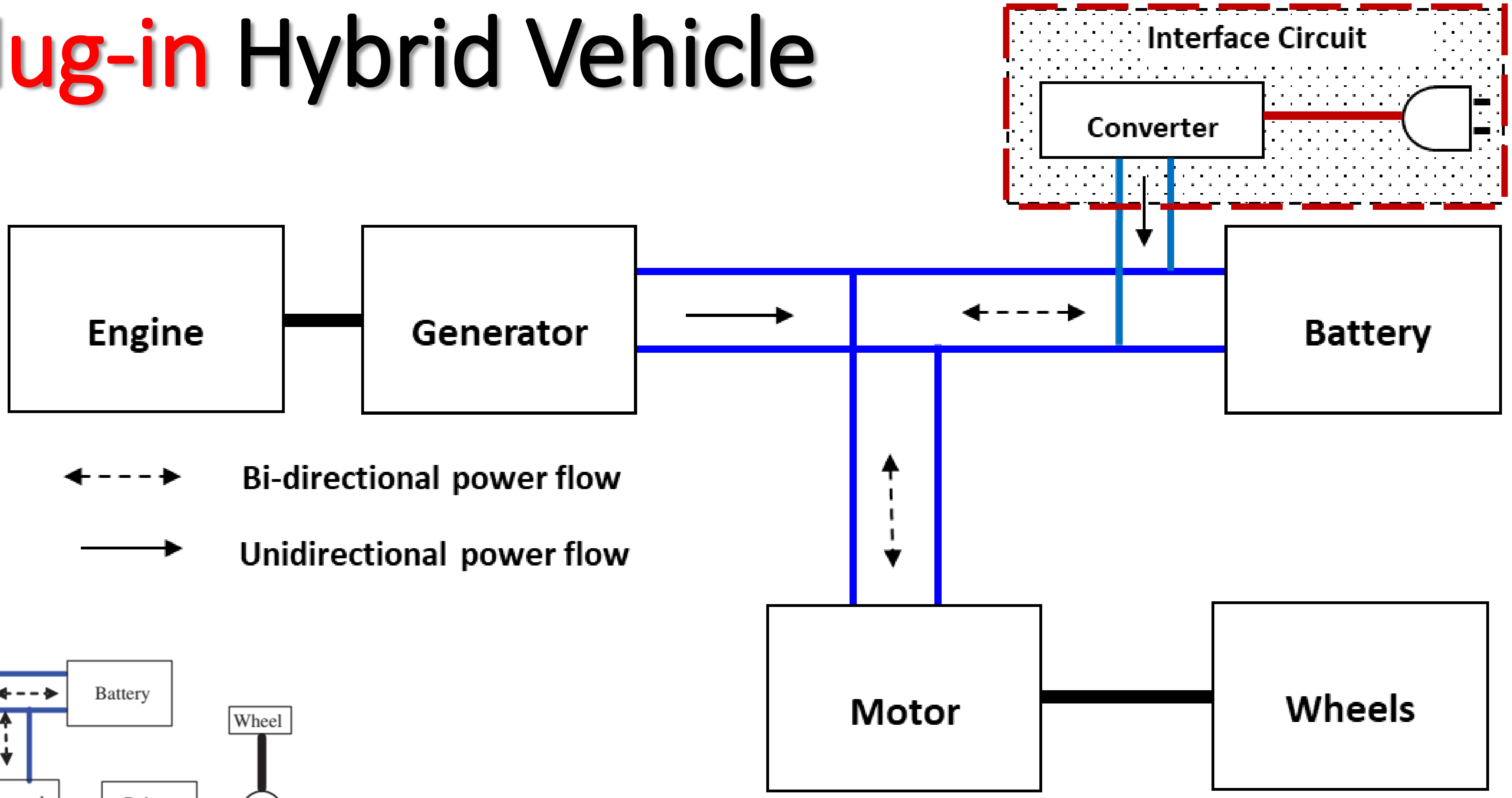


FIGURE 3.9 Block diagram of a series PHEV.

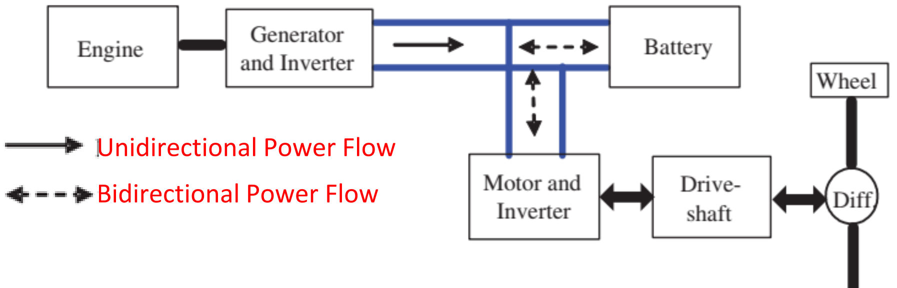
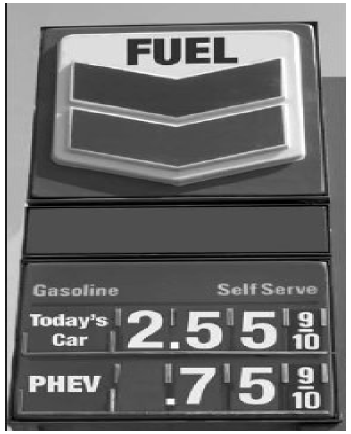


FIGURE 3.2 Series HEV powertrain.

Advantages of PHEV

- Unlike EVs frequent recharging is not required. One recharge per month may be sufficient for PHEV's.
- Maintenance cost is less since the vehicle is primarily electric.
- Vehicle-to-grid
  - PHEV's can help the grid during peak loads.
  - They would even out electricity demand (which is typically higher in the day time) and provide a greater return on capital for electricity infrastructure.



Disadvantages of PHEV

- The additional batteries used in PHEV will add weight.
- The cost of the batteries will be high since they have to be replaced within a life cycle of the vehicle.
- The PHEVs may be expensive than the HEVs because of the large battery packs and the additional electronic circuitry for charging these batteries.
- Producing power from the grids to charge the PHEVs will produce additional emissions.
- The mileage gain by PHEVs are highly dependent upon the way the vehicle is used and the opportunities to recharge by plug.

Electric Vehicles: Skateboard Chasis

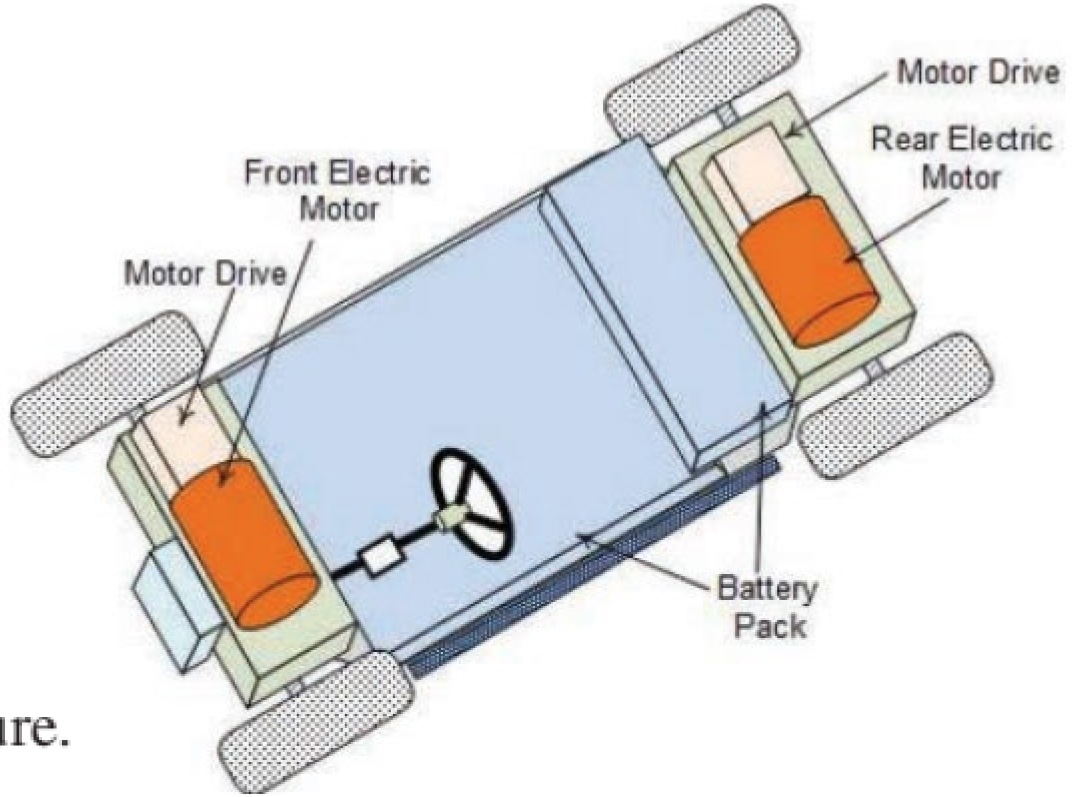
- The BEVs have high acceleration performance, quiet and smooth power, wide torque range, lower operating costs and minimal maintenance.
- Enabling numerous new concept or architecture of manufacturing
- The simplicity and flexibility in packaging the electric powertrain within the chassis of the vehicle.
- Propulsion components is the electric motor: powering one or more axles or mounted on the wheel hub.
- The electric motor and inverter ratings of the electric powertrain determine the propulsion capability of the vehicle.
- The energy storage or battery capacity determines the range of the vehicle on a full charge.

Electric Vehicles: Skateboard Chasis

- The electric powertrain (e-powertrain) is a combination of an electric motor, inverter and gearbox.
- It is place in an axle of a vehicle known as the e-axle.
- Skateboard chassis is a concept where the energy source and e-powertrain for the vehicle are enclosed within the chassis.
- The skateboard concept has been adopted more recently by Tesla, Rivian and other EV manufacturers.
- The skateboard design provides greater vehicle design freedom, more usable passenger space and a modular platform to increase production scale.
- With an e-powertrain concept, it is possible to design heavier vehicles with more than e-axles.

Electric Vehicles: Skateboard Chasis

FIGURE 3.11 Skateboard chassis layout for EVs.



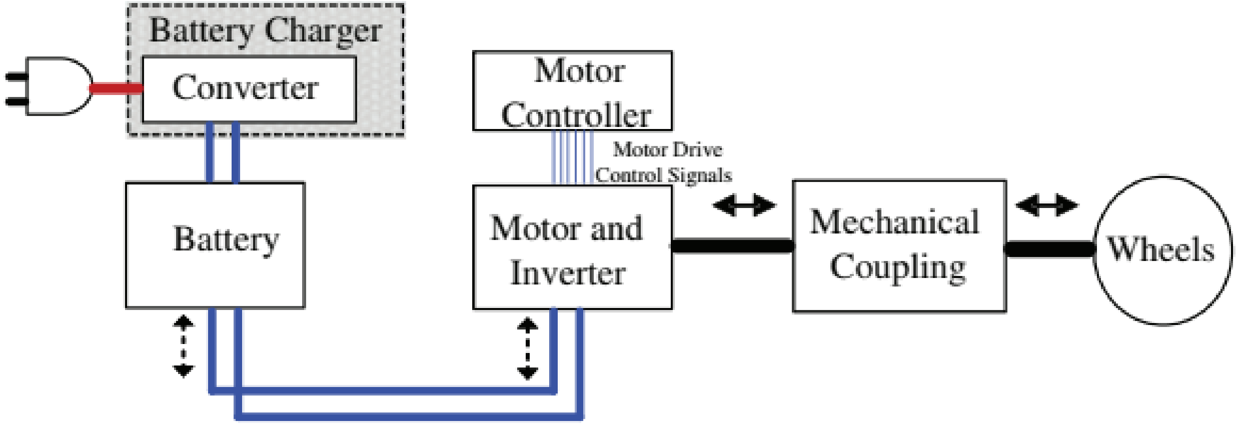
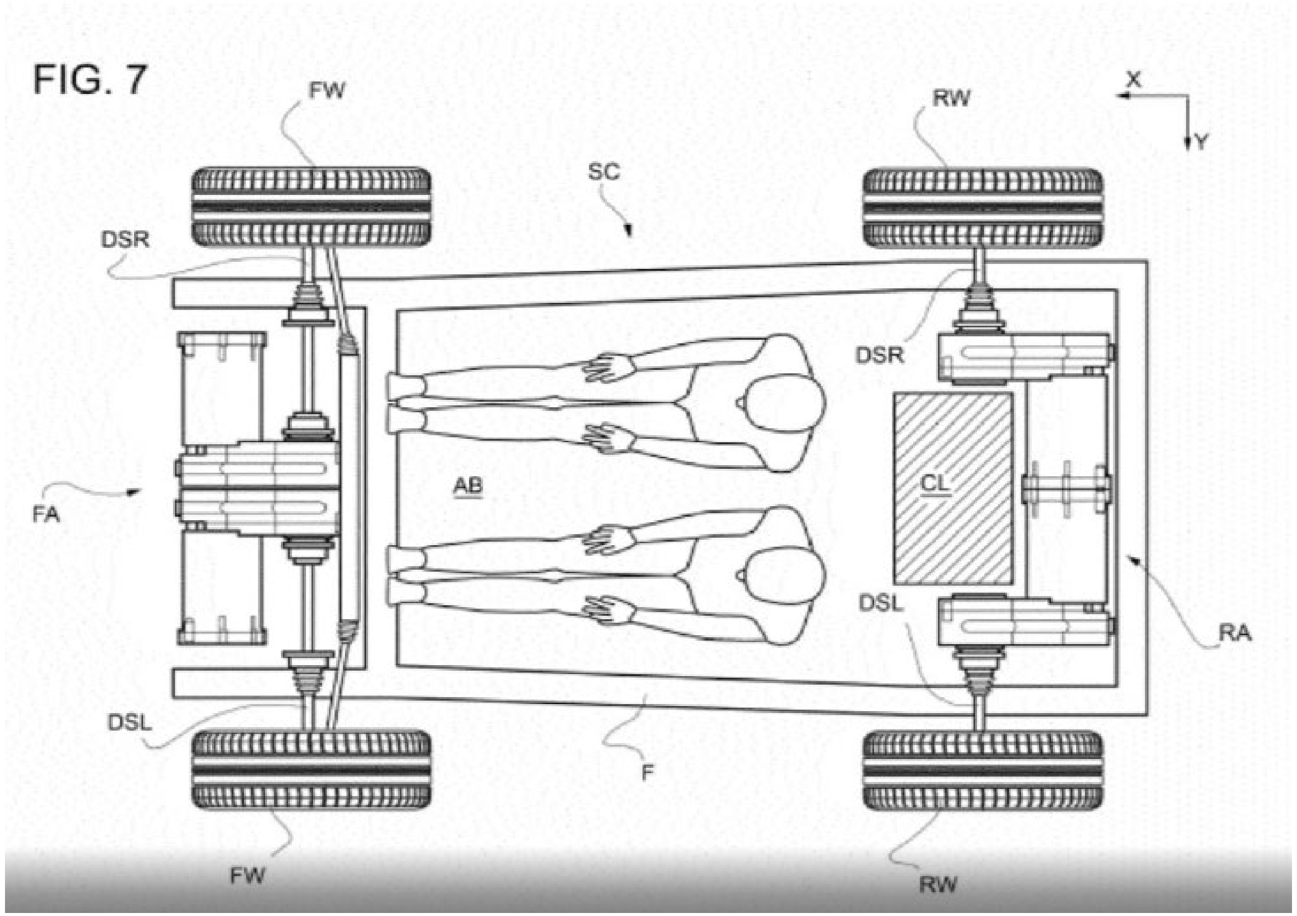


FIGURE 3.10 EV equivalent powertrain architecture.

Ferrari's new patent reveals a modular EV architecture

By Sagar

Posted on January 26, 2020



Powertrain Component Sizing

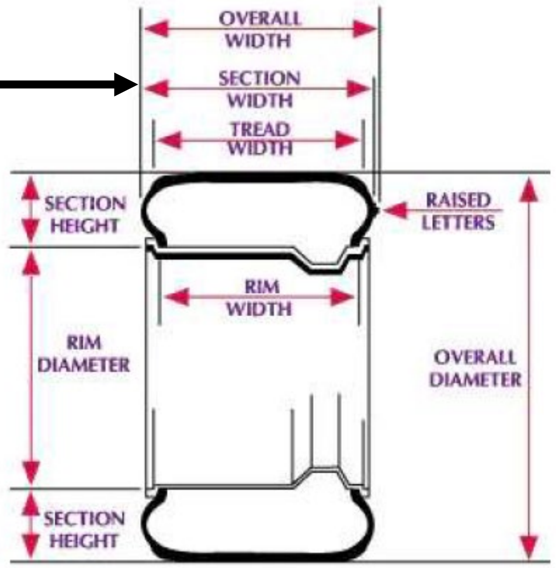
EV Motor Sizing

- Three segments in torque-speed envelope are:
  - Constant torque region
  - Constant power region
  - Natural mode region
- Size of electric motor varies with the maximum torque required from the machine
- Motors are designed for high speed operation to minimize size and weights
- Gears are used to match higher speeds
- Typical motor speeds—15000rev/m for wheel speeds around 1000rev/m

Example

145/80R10

AR(in%) =SH/SW



Tire Size Chart - Metric - by Rim/Wheel Diameter

Charts ▸ Tire Size Chart - Metric - by RD

Tire Size Chart - Metric - by Rim/Wheel Diameter displays the **metric tire size designations** with belonging tire measures:

OD - Overall Tire Diameter, **SW** - Section width, **AR** - Aspect Ratio, **RD** - Rim diameter, **SH** - Section height, **CI** - Tire circumference, **RE** - Revolutions per mile/km; **in metric and English units**.

Metric tire size designations are grouped by a rim diameter - there is one chart for each rim diameter, which you can select by clicking the appropriate link.

The chart data can be filtered and sorted by each column with a click on the appropriate table column heading.

More information on how to use the charts on this page: How to use the charts.

Please choose a rim/wheel diameter:

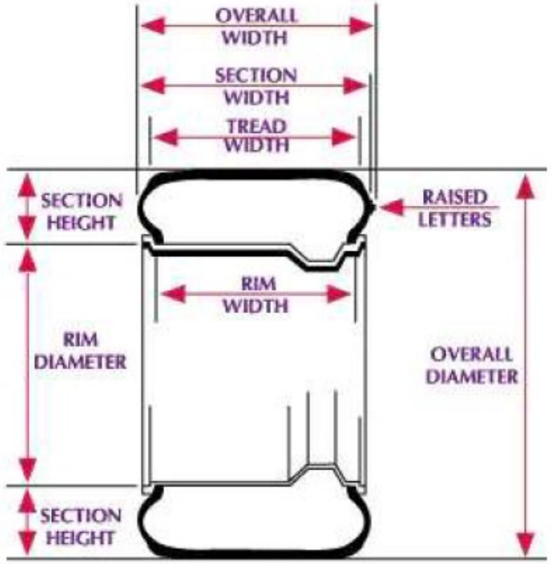
10" 12" 13" 14" 15" 16" 17" 18" 19" 20" 21" 22" 23" 24" 25" 26" 28"
30" 32"

https://www.tyresizecalculator.com/charts/tire-size-chart-metric-by-rim-wheel-diameter

Example

➢ A vehicle with a typical tire dimension is given below

Tire Size Designation	OD (mm)	OD (in)	SW (mm)	SW (in)	AR	SH (mm)	SH (in)	CI (mm)	CI (in)	RE (km)	RE (mile)
145/80R10	486	19.1	145	5.7	80	116	4.6	1526	60.1	655.3	1054.2
155/80R10	502	19.8	155	6.1	80	124	4.9	1576	62.1	634.5	1020.3
165/70R10	485	19.1	165	6.5	70	116	4.5	1523	60.0	656.6	1056.0



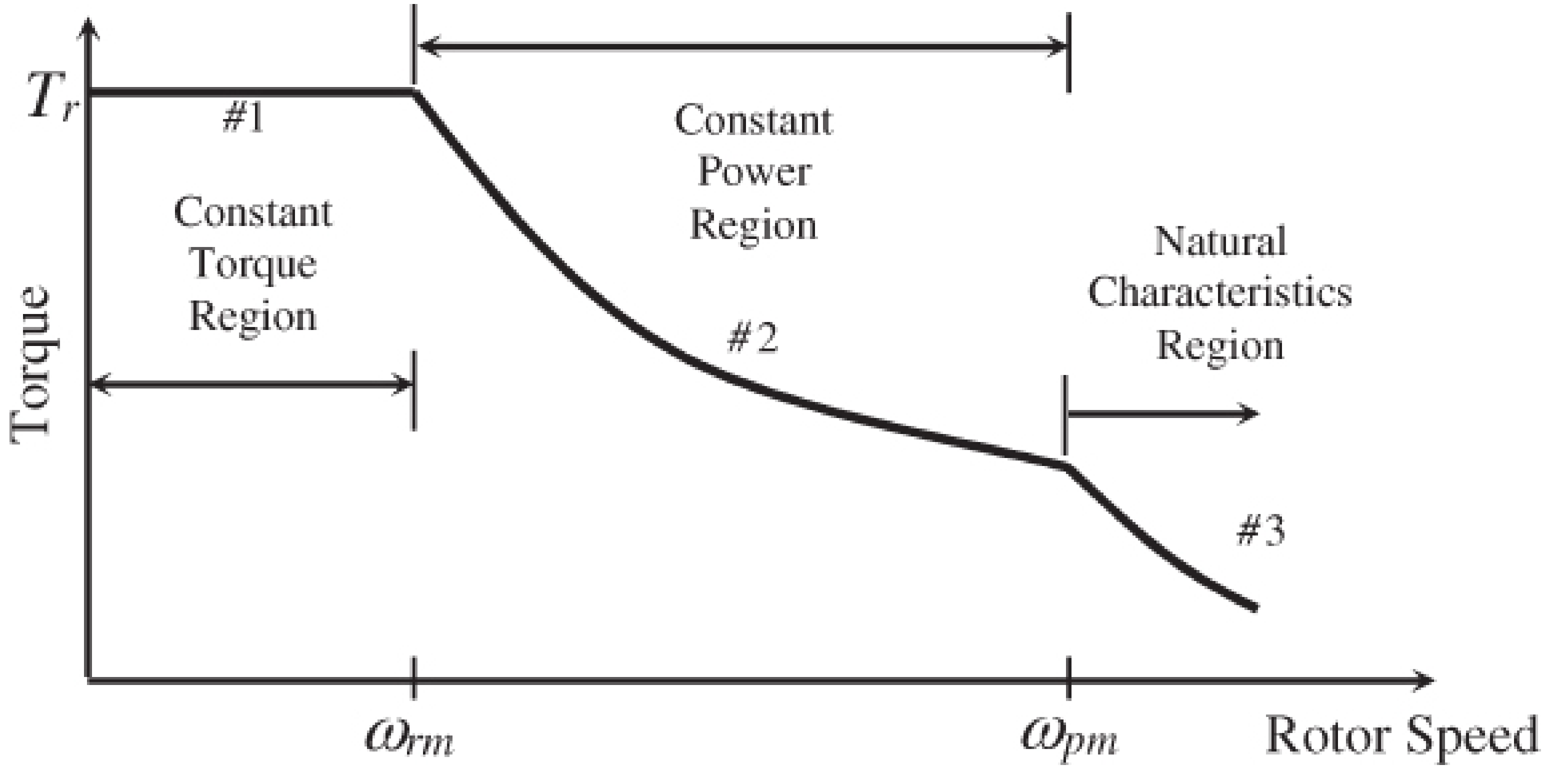
How do you compute the angular speed (in rpm) of the engine driving the wheel via the transmission with a gear ratio (GR)

$$GearRatio\left(w_{engine}, w_{wheel}\right) := \frac{w_{engine}}{w_{wheel}}$$

Compute the speed of the vehicle (m/s) given the wheel radius (tire radius in m), and the rotational speed of the wheel (rad/s)

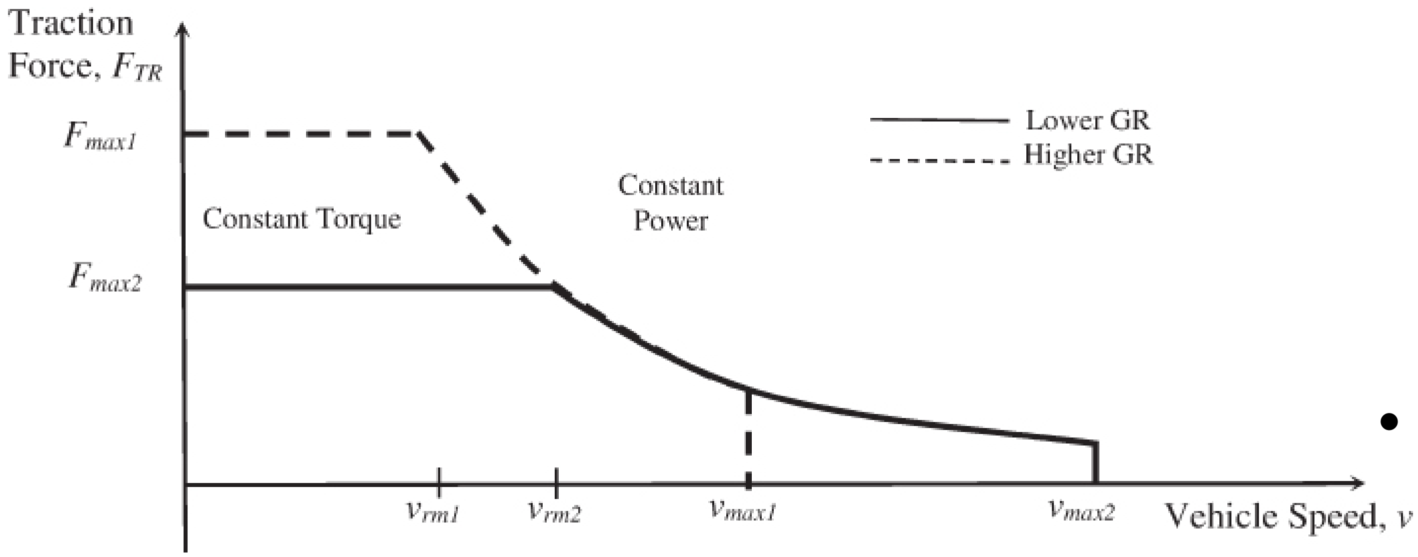
$$v_{vehicle}\left(\omega_{wheel}, R_{tire}\right) := \omega_{wheel} \cdot R_{tire}$$

EV Motor Sizing



Electric motor torque-speed envelope

EV Motor Sizing



Electric Motor torque-speed characteristics in terms of traction force and vehicle speed for two gear ratios

- Gear ratio depends on
  - motor rated speed
  - Vehicle maximum speed
  - Wheel radius
  - Maximum gradability
- Higher GR means larger gear size
- GR and electric motor rated speed to be selected simultaneously to optimize the overall size and performance requirements

Design of Electric Motor

- Requirements:
  - Initial acceleration
  - Rated velocity on a given slope
  - Maximum steady-state velocity
  - Maximum gradeability

Kinetic Energy
(joule or watt-sec)

$$E_m = \frac{1}{2} m \left(v_{rm}^2 + v_f^2\right)$$

- Initial (linear) acceleration $$a = \frac{dv}{dt} = \frac{F_{TR} - F_{RL}}{m}$$

Power (in watt)

$$P_m = \frac{dE_m}{dt} = \frac{\frac{1}{2} m \left(v_{rm}^2 + v_f^2\right)}{t_f}$$

- The motor power rating is $$P_m = \frac{m}{2t_f}\left(v_{rm}^2 + v_f^2\right)$$

t_f = time needed to accelerate from v_{rm} to v_f

- ❑ Smallest motor required for operating in the constant power mode, $V_{rm} = 0$

Rated Vehicle Velocity (v_{max})

The traction power required to cruise the vehicle at maximum vehicle velocity v_{max} is

$$P_{TR,max} = mgv_{max}\sin\beta + \left[mgC_1 + \frac{\rho}{2}A_F C_D\right]{v_{max}}^3 + mgv_{max}C_0$$

$$F_{TR,max} = \frac{P_{TR,max}}{v_{max}}$$

The maximum gradability of a vehicle for a given motor and gear ratio can be derived from

$$\text{Max.grade} = \frac{100F_{TR}}{\sqrt{(mg)^2 - {F_{TR}}^2}}$$

Typical IC Engine Characteristics

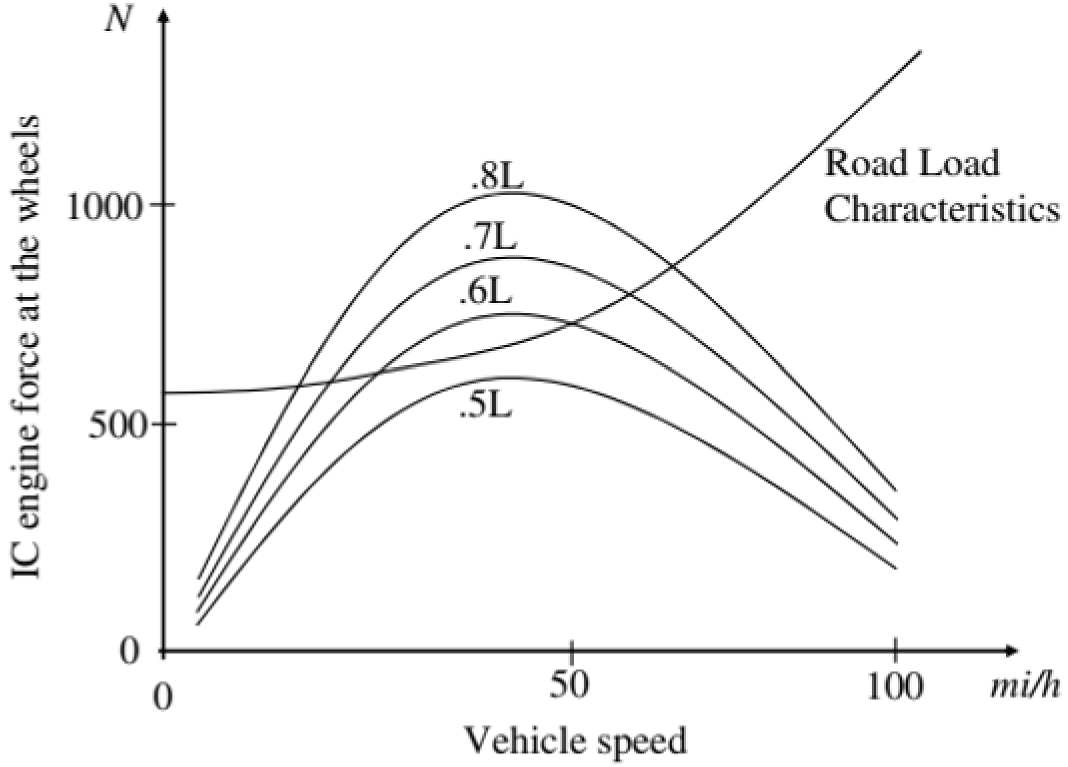


FIGURE 3.14 Typical IC engine force-velocity characteristics and road-load characteristics

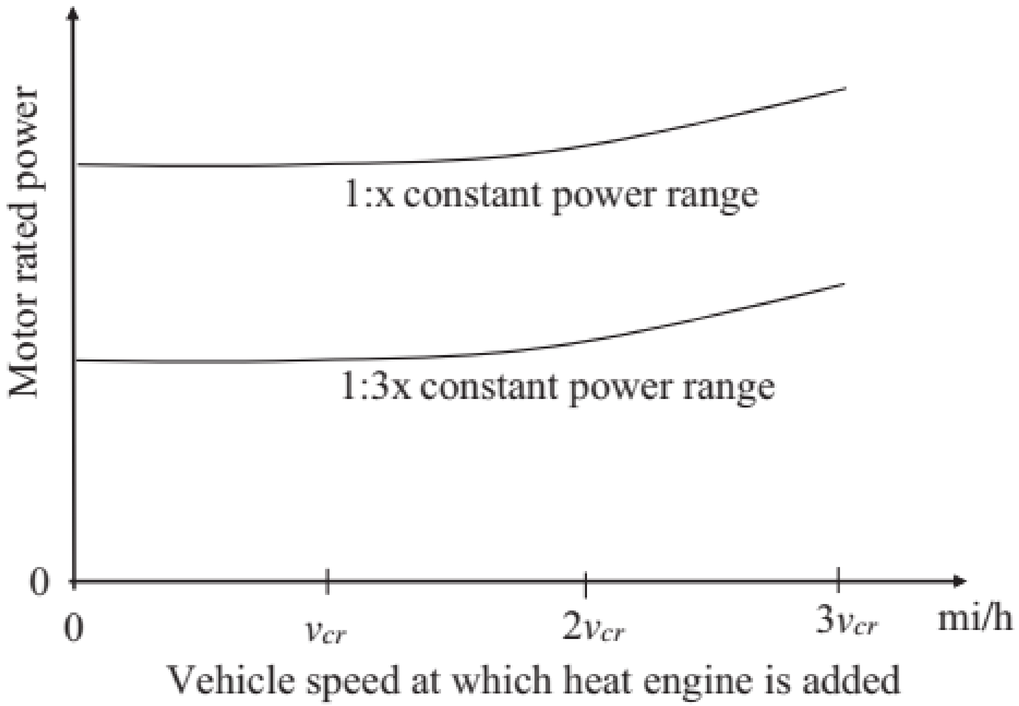
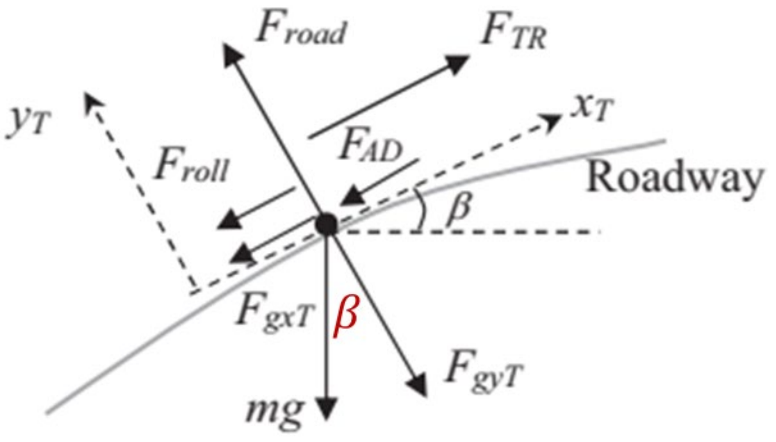


FIGURE 3.15 Electric power requirement as a function of vehicle speed at which IC engine is added

Design of Electric Motor

- Rated vehicle velocity:
  - The drivetrain designed to accelerate the vehicle from 0 to rated velocity will always have the sufficient power to cruise the vehicle at rated speed



- Maximum velocity:
  - The traction power required to cruise the vehicle at maximum vehicle velocity v_{max} is $P_{TR,max} = F_{TR} \cdot v_{max}$

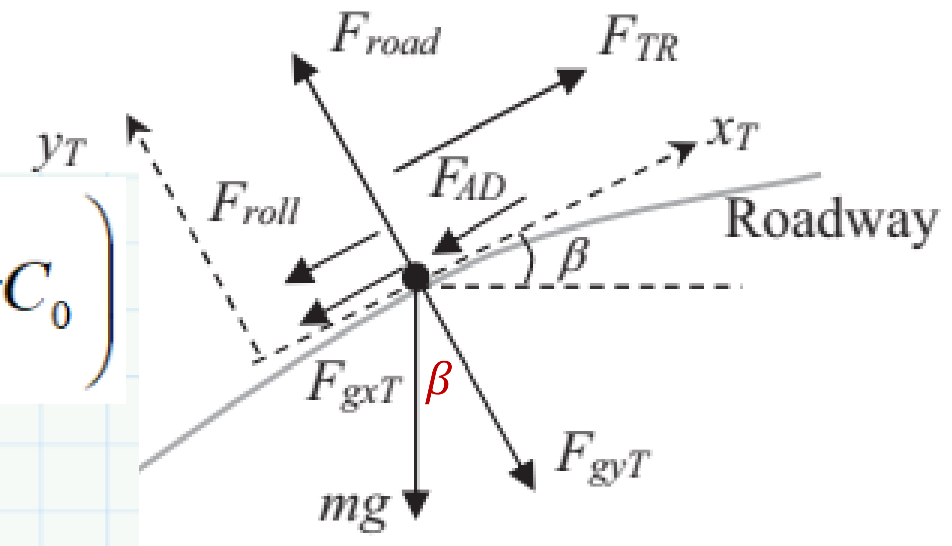
$$P_{TR,max} = \overbrace{mgv_{max}\sin\beta}^{F_{gxT}\,v_{max}} + \Big[\overbrace{mgC_1}^{F_{roll\_1}\,v_{max}} + \overbrace{\frac{\rho}{2}A_F C_D}^{F_{AD}\,v_{max}}\Big]v_{max}{}^3 + \overbrace{mgv_{max}C_0}^{F_{roll\_0}\,v_{max}}$$

- ❑ A_F = vehicle frontal area
- ❑ C_D = aerodynamic coefficient of drag
- ❑ C_0 and C_1 = rolling resistance coefficients

- The dominant resistance force at high speeds is the aerodynamic drag force.

$F_{roll\_0} = m\,g\,C_0$, $F_{roll\_1} = m\,g\,C_1 v^2_{max}$, $F_{AD} = 0.5\,\rho\,A_F\,C_D v^2_{max}$, $F_{gxT} = m\,g\,\sin(\beta)$

Example Equation 3.3:



$$P_{TR}(t) = V\left(mg\sin\beta + \left[mgC_1 + \frac{\rho}{2}A_F C_D\right]V^2 + mgC_0\right)$$

$\rho := 1.23 \cdot 10^{-3} \cdot \frac{kg}{m^3}$ Air density in $\frac{kg}{m^3}$

The caculation of the Forces acting on the vehichle must be overcome by the motor. The Forces (in N) can be written as a function with the input $(v, m, \beta, C_0, C_1, C_D, A_F)$

The power required by the motor can be computed from the Force x vehicle speed

$$F_{TR}(v_{tot}, m, \beta, C_0, C_1, C_D, A_F) := \left(m \cdot g \cdot \sin(\beta) + \left(m \cdot g \cdot C_1 + \frac{\rho}{2} \cdot A_F \cdot C_D\right) \cdot {v_{tot}}^2 + m \cdot g \cdot C_0\right)$$

$$P_{TR}(v, v_{tot}, m, \beta, C_0, C_1, C_D, A_F) := v \cdot \left(m \cdot g \cdot \sin(\beta) + \left(m \cdot g \cdot C_1 + \frac{\rho}{2} \cdot A_F \cdot C_D\right) \cdot {v_{tot}}^2 + m \cdot g \cdot C_0\right)$$

$$F_{TR}(v_{tot}, m, \beta, C_0, C_1, C_D, A_F) := \left(m \cdot g \cdot \sin(\beta) + \left(m \cdot g \cdot C_1 + \frac{\rho}{2} \cdot A_F \cdot C_D\right) \cdot {v_{tot}}^2 + m \cdot g \cdot C_0\right)$$

$$P_{TR}(v, v_{tot}, m, \beta, C_0, C_1, C_D, A_F) := v \cdot \left(m \cdot g \cdot \sin(\beta) + \left(m \cdot g \cdot C_1 + \frac{\rho}{2} \cdot A_F \cdot C_D\right) \cdot {v_{tot}}^2 + m \cdot g \cdot C_0\right)$$

where the input variables are

F_{TR} is the traction force in Newton P_{TR} is the traction power in Watts

v is the speed of the vehicle in m/s

v_{tot} is the wind speed exposed to the vehicle frontal area including headwind

m is the total mass of the vehicle, passengers, driver, and loads (kg)

β is the angle used to define the slope x of the road computed as $\beta = asin(x\%)$

C_o (per unit) and C_1 in $\left(\frac{Newton}{Watt}\right)^2$ are the rolling coefficients

C_D is the aerodynamic drag coefficient (in per unit)

A_F is the vehicle frontal area (in m^2)

Example Equation 3.3:

Given the input data for the Vehicle #1 as follows:

$v_{max} := 75 \cdot mph$ $\beta := \operatorname{asin}(3\%) = 1.719\ deg$ $C_0 := 0.01$ $C_D := 0.4$ $A_F := 2.6\ m^2$

$m_v := 1800\ kg$ $C_1 := 1 \cdot 10^{-9} \cdot \left(\frac{N}{W}\right)^2$ $m_{perperson} := 80\ kg$ $v_{headwind} := 20 \cdot mph$

$m := m_v + 2 \cdot m_{perperson} = \left(1.96 \cdot 10^3\right)\ kg$ $v_{tot} := v_{max} + v_{headwind} = 95\ mph$

$v_{tot} = 42.469\ \frac{m}{s}$

Calculate the components of the F_{TR} of the Vehicle #1:

$F_{slope} := m \cdot g \cdot \sin(\beta) = 576.631\ N$

F_{slope} (N) = component of the force that the motor required to hold the vehicle in position against the gravity on a hilly road.

$F_{AD} := \frac{\rho}{2} \cdot A_F \cdot C_D \cdot {v_{tot}}^2 = 1.154\ N$

F_{AD} (N) = component of the force that the motor required to drive against the aero drag

$F_{roll\_1} := m \cdot g \cdot C_1 \cdot {v_{tot}}^2 = 0.035\ N$

F_{roll_1} (N) = component of the force that the motor power required to drive against the wind drag

$F_{roll\_0} := m \cdot g \cdot C_0 = 192.21\ N$

F_{roll_0} (N) = component of the force that the motor required to drive against the wind drag

$F_{TR}(v_{tot}, m, \beta, C_0, C_1, C_D, A_F) = 770.03\ N$

F_{TR} (N) = the total motor traction force

P_{TR} (W) = the total motor traction power

$P_{TR}(v_{max}, v_{tot}, m, \beta, C_0, C_1, C_D, A_F) = 25.818\ kW$

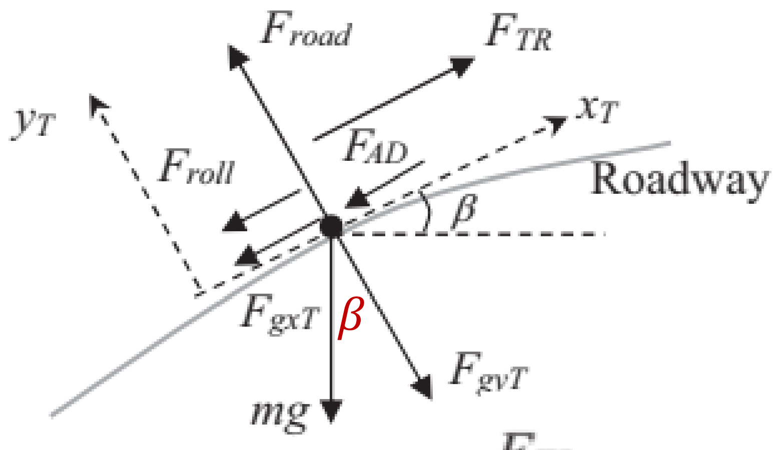
$P_{TRcalc} := F_{TR}(v_{tot}, m, \beta, C_0, C_1, C_D, A_F) \cdot v_{max} = 25.818\ kW$

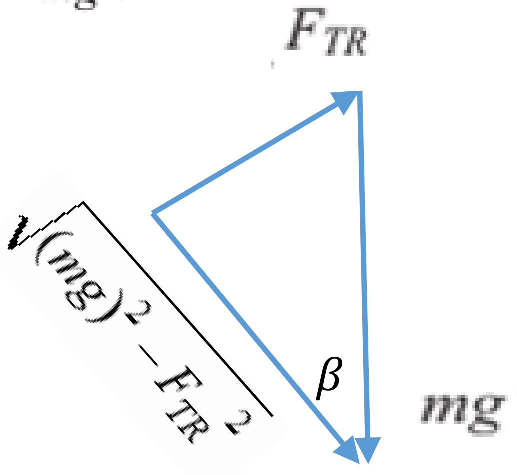
Design of Electric Motor

- 3.5.2.4 Maximum gradeability:

  The maximum gradeability of a vehicle for a given motor and gear ratio can be derived from

Slope = tan(β) = $$\text{Max.}\,\%\,\text{grade} = \frac{100F_{TR}}{\sqrt{(mg)^2 - F_{TR}^{\;2}}}$$

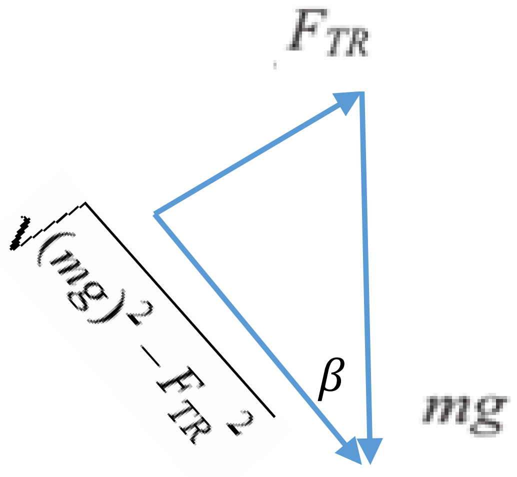




- If the maximum electric motor power derived for acceleration or maximum vehicle velocity is not enough to meet the maximum gradeability requirement of the vehicle, then either the motor power rating or the gear ratio has to be increased.

Example:

$$\text{Max. \% grade} = \frac{100F_{TR}}{\sqrt{(mg)^2 - F_{TR}{}^2}}$$



Given the total fraction force $FTR := 770\ N$

Total mass = m = 1960 kg $m \cdot g = \left(1.922 \cdot 10^4\right)\ N$

Calculate the maximum % grade

$$Max\_pct\_grade(m, g, FTR) := 100 \cdot \frac{FTR}{\sqrt{(m \cdot g)^2 - FTR^2}}$$

$$Max\_pct\_grade(m, g, FTR) = 4.009$$

HEV Powertrain Sizing

- Design Philosophy
  - Electric motor to supply power for acceleration and urban driving (series mode)
  - Generator to be sized for urban driving series operation
  - ICE to deliver power during the charge sustaining mode (cruising at rated velocity)
  - Energy storage to be sized for acceleration and zero emission range

Initial Acceleration

- Power required during acceleration is sufficient to meet maximum velocity and towing requirements
- Peak acceleration power comes from both electric machine and IC engine
- Acceleration is under constant torque (e.g., T_{rated}) initially until the peak power limit of the powertrain is reached. The powertrain then works in constant power mode.

Initial Acceleration

- **Constant Force Equations**

$$v(t) = \sqrt{\frac{K_1}{K_2}} \tanh\left(\sqrt{K_1 K_2}\, t\right)$$

where

$$K_1 = \frac{F_{TR}}{m} - gC_0 - g\sin\beta \quad > 0$$

$$K_2 = \frac{\rho}{2m} C_D A_F + gC_1 \quad > 0$$

- **Constant Power Equations**

$$\frac{dv}{dt} = \frac{P_{TR}}{mv} - K_3 - K_4 v^2$$

where

$$K_3 = gC_0 + g\sin\beta$$

$$K_4 = \frac{\rho}{2m} C_D A_F + gC_1$$

Initial Acceleration

- **Constant Acceleration**

$$v(t) = a\,t$$

where v(t) = speed in m/s and
a = acceleration in m/s^2

For example for acceleration of speed from 0–60 mph in 9 s, the constant acceleration a can be computed as a = 2.98 m/s^2

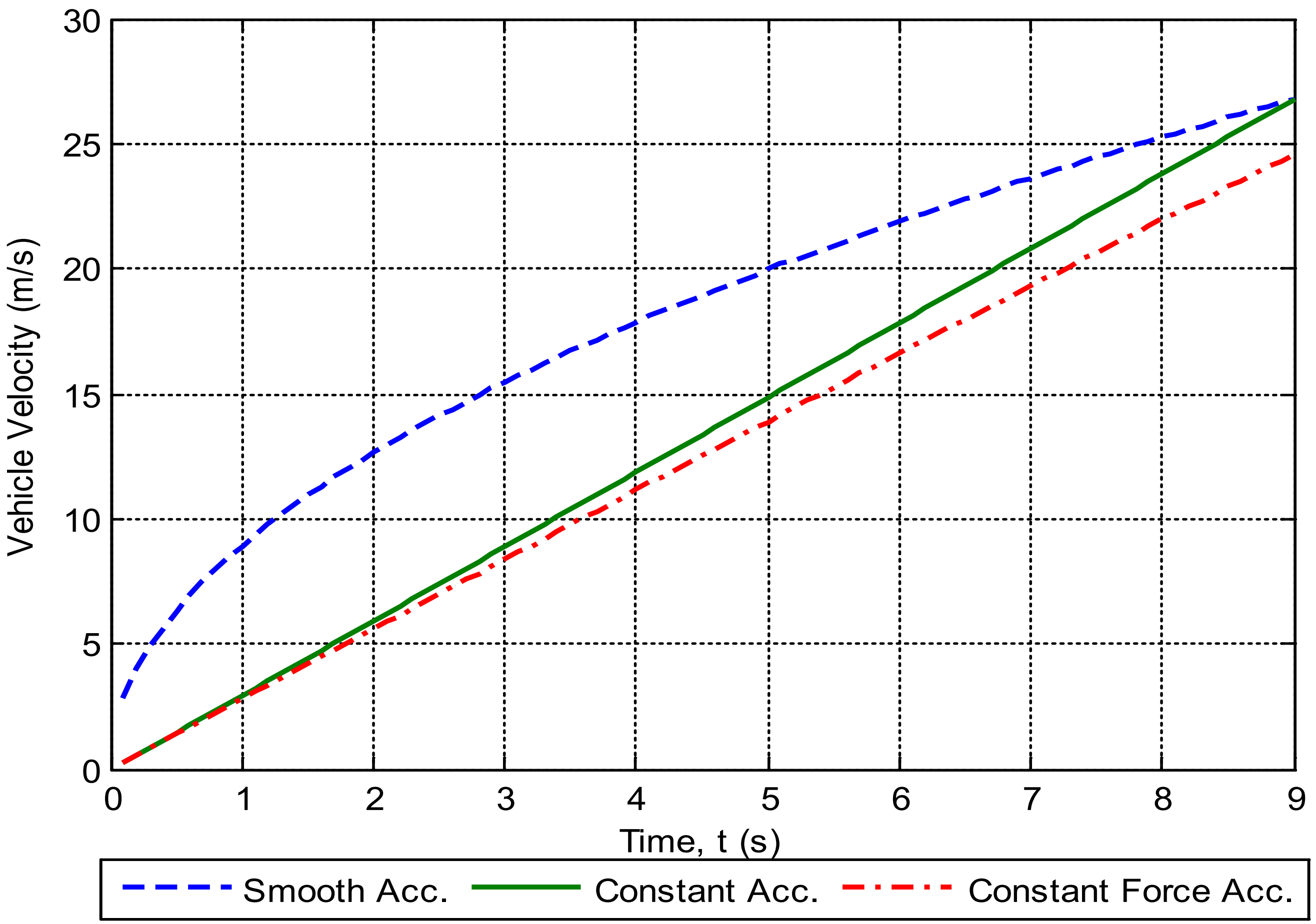
- **Smooth acceleration can be derived as**

$$v(t) = v_f\left[\frac{t}{t_f}\right]^x$$

where $v(t)$ = speed in m/s
v_f = final speed (e.g., $60\ mph = 26.822\ \frac{m}{s}$)
t_f = time to reach v_f (e.g., 9 sec)
x = 0.47 to 0.53

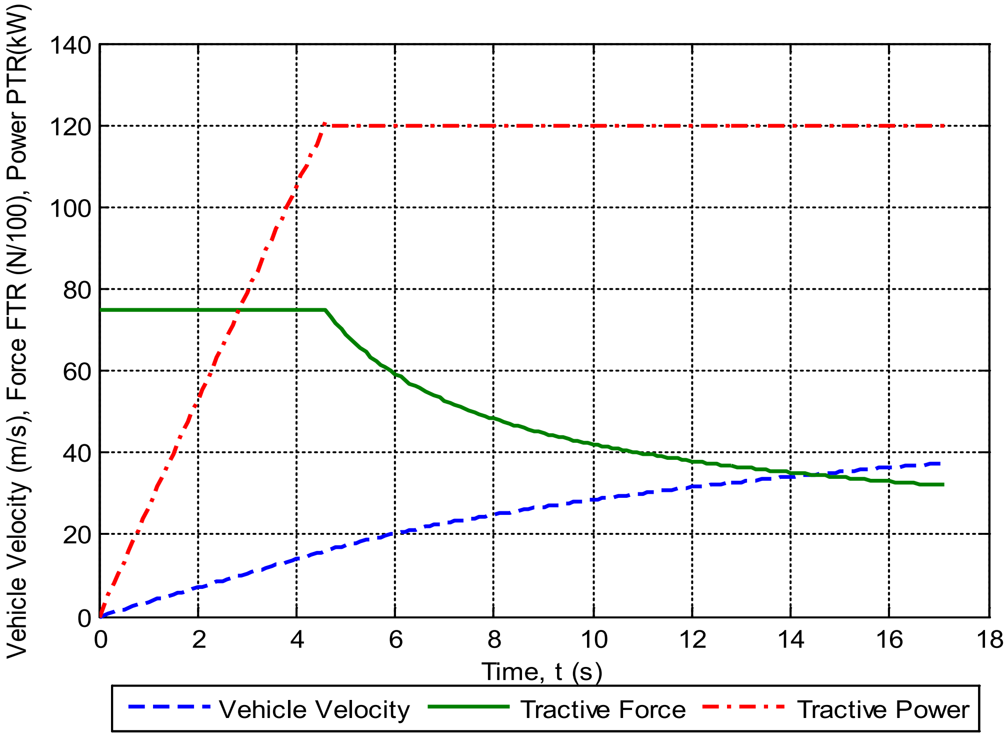
Akron HEV Vehicle Technical Specifications (VTS)

Description	**Requirements**
Vehicle Mass	4400 Lbs./ 1995 kg
Driver/One passenger	176 Lbs./ 80 kg
Trailering Capacity	2500 Lbs./ 1133 kg
Rolling Resistance Coefficient, C_0	0.009
Wheel Radius, r_{wh}	0.3305 m
Aerodynamic Drag Coefficient, C_{AD}	0.45
Frontal Area, A_F	2.686m^2
0-60 MPH	9.0s
50-70 MPH	6.8s



Velocity profiles for three types of acceleration

Tractive Force and Power



Assuming 90% drivetrain efficiency, the minimum combined power is 132kW

$F_{TR,peak}$	$P_{TR,peak}$	Time and velocity of mode transition	Time for 0-60 mph	Time for 50-70 mph
7500N	120kW	4.6 sec/ 16 m/s	9 secs.	5 secs.

Cruising Speed

- The HEV IC engine can be sized for the engine power required to maintain a steady expressway velocity of *x* mph (say 75), up a *x*% grade (say 3%), and against a *x mi/h* (say 20) headwind at high engine fuel efficiency.
- In the UA HEV, the engine is sized for 55mph cruising speed with 2500Lbs of trailer load up a 7% slope
- Constant velocity power requirement

$$P_{TR}(t) = V\left(mg \sin\beta + \left[mgC_1 + \frac{\rho}{2} A_F C_D \right] V^2 + mgC_0 \right)$$

The engine power required is 108hp or 81kW

Akron HEV Generator Sizing

- The generator is sized to maintain series operation for typical urban driving conditions.

For a constant velocity of 40mph with a driver and a passenger on a 1% grade and 10% drivetrain losses requires 12kW. Allowing for 15% losses, the generator size is 15kW

Akron HEV Energy Storage Sizing

- The energy required by the electric motor for initial acceleration to be calculated to estimate the size of the Ultracapacitor bank. The energy required is 1.62MJ or 450Whr
- The energy required for cruising at constant velocity of 40mph with a driver and a passenger on a 1% grade and 10% drivetrain losses is 3kWhr for a 10 mile (15 minute) or 1.5kWhr for a 5 mile (7.5 minute) battery-only range .
- For a 300V battery, this requires a 10 Ahr or 5 Ahr battery-pack.

Mass Analysis and Packaging

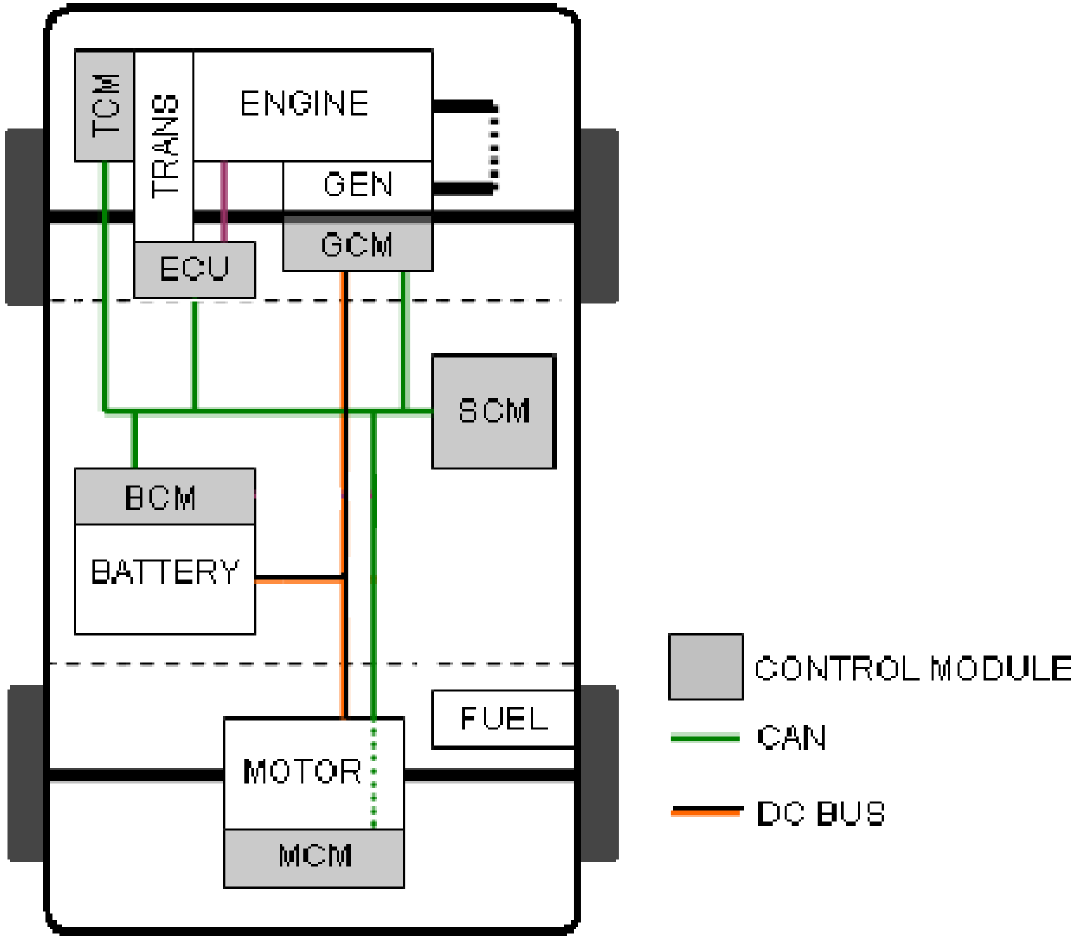
- Vehicle mass budget need to be assessed during design
- Fuel economy and emissions improve as mass goes down
- Hybrids tend to be heavier compared to a similarly sized ICEV
- Downsized engine in the hybrid can more than make up for the masses added due to hybridization

Mass comparison of ICEV and its re-engineered HEV

Component	ICE Vehicle Mass, kg	Hybrid Vehicle Mass, kg
Engine and Transmission	147	125
Exhaust System	40	50
Fuel system (tank and lines)	13	9
Fuel Mass	38	15
Electric Drive Motor		108
Starter/generator	6	22
Starter/generator controller		26
Electrical thermal management		15
Traction battery		75
Battery hardware, cooling		28
12V battery	14	6
Alternator	5	
Total powertrain	263	479
Climate control and accessory	26	30
Glider with Chassis Subsystems	1445	1449
Total Curb mass	1734	1954

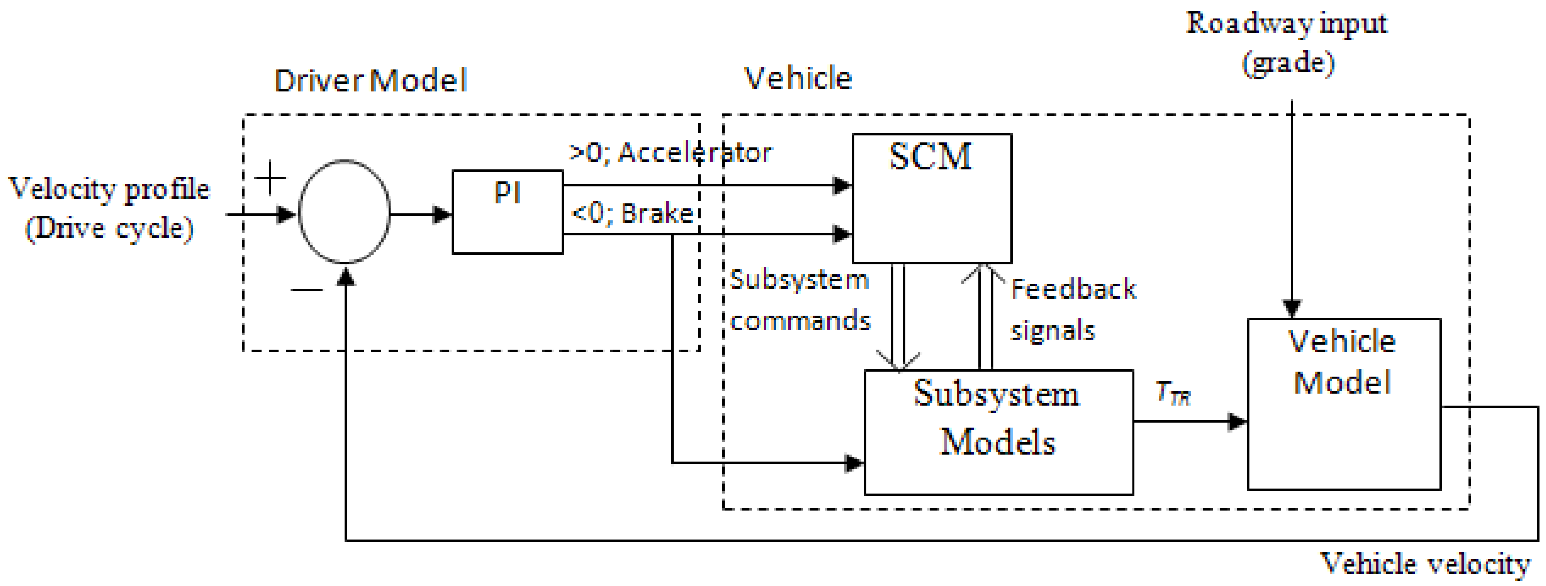
The vehicle is a Chevrolet Equinox crossover SUV

Component Packaging



Vehicle Simulation

- Simulation using standard driving cycles saves time and cost in predicting vehicle performance and energy usage.
- At global system level, simulation can predict fuel economy, wheel torque and emissions
- At the sub-system level, component parameters such as electric machine or engine torque are available
- Simulation model can be used to tune supervisory controller

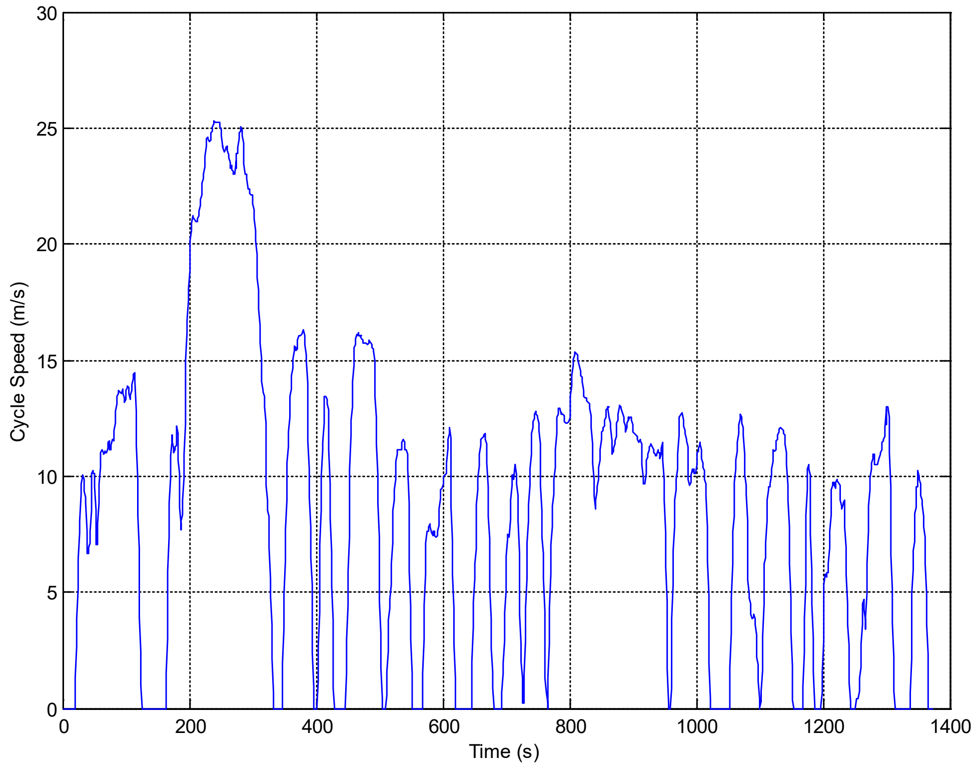


Standard Driving Cycles

- Standard driving cycles are used by governmental agencies and automotive industry for performance evaluation
- Standard drive cycle may have one or both of speed and road grade components
- Commonly used drive cycles are urban dynamometer driving schedule (UDDS) and highway fuel economy test (HWFET) cycles
- Other example cycles are US06 and Japan1015 standard drive cycles

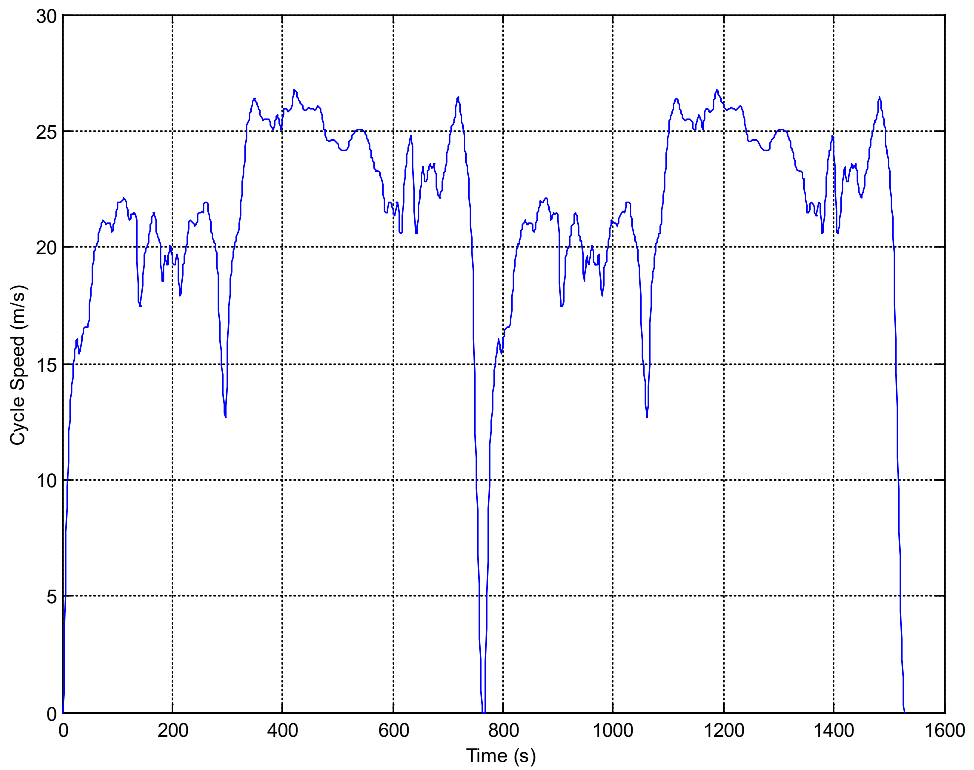
UDDS Drive Cycle

- UDDS cycle runs for 7.5 miles in 1369 seconds with frequent stops and an average speed of 19.6 mph



HWFET Drive Cycle

HWEFT runs for a distance of 10.26 miles in 765 secs with an average speed of 48.3 mph

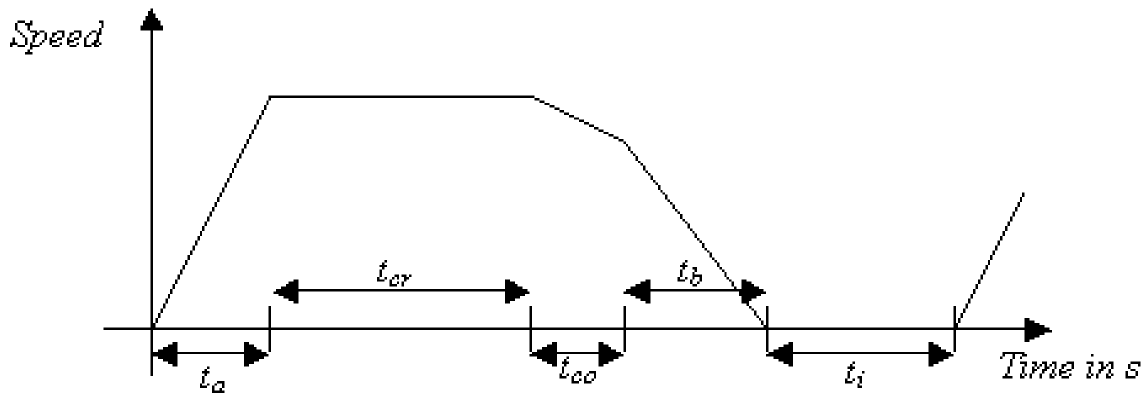


SAE J227a Drive Cycles

The SAE J227a has three schedules designed to simulate the typical driving patterns of fixed-route urban B, variable-route urban C and variable-route suburban travels D

Table 3.5 SAE J227a standard driving schedules

Test Parameter	SAE J227a schedules		
	B	C	D
Max. speed, km/h (m/h)	32	48	72
Acceleration time, t_a s	19	18	28
Cruise time, t_{cr} s	19	20	50
Coast time, t_{co} s	4	8	10
Brake time, t_{br} s	5	9	9
Idle time, t_i s	25	25	25
Total time, s	72	80	122
Approximate number of cycles per mile	4-5	3	1



SAE J227a standard driving cycle.