Hybrid Electric Vehicle**: EE 6620E**

Module 1

Presented by

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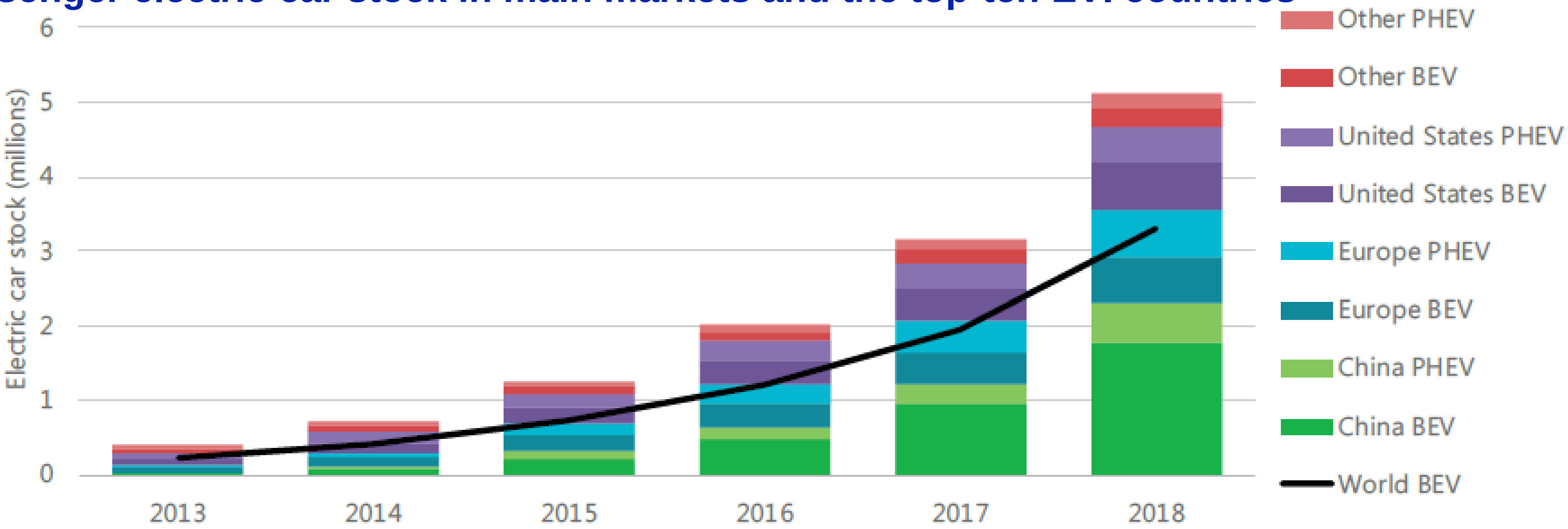
Growth of EV

Passenger electric car stock in main markets and the top-ten EVI countries



Notes: BEV = battery electric vehicle; PHEV = plug-in electric vehicle. Other includes Australia, Brazil, Chile, India, Japan, Korea, Malaysia, Mexico, New Zealand, South Africa and Thailand.

- ✓ Lithium-ion battery manufacturing consists of three parts. First is cell to battery-pack manufacturing involving a value-add of 30 to 40%. The second is cell manufacturing with a value add of 25 to 30%. The third involves battery-chemicals with a value of 35 to 40% of the total cost of battery pack.
- ✓ India needs a minimum of 10 GWh of cells by 2022, which would need to be expanded to about 50 GWh by 2025.
- ✓ Therefore, manufacturing these cells in India would be encouraged. It is imperative that India gets the cell-cost and parameters like energy-density (size and weight), life-cycles, safety, temperature tolerance right, so that its batteries are best in the world.

Requirements of EV

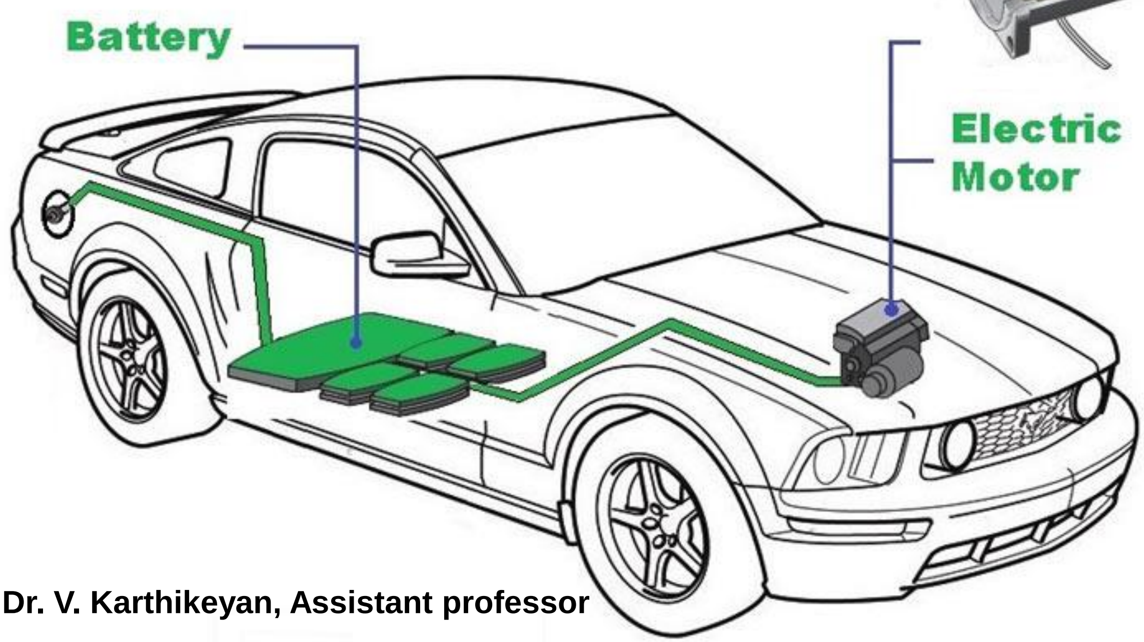
- ✓ Being safe and causing no environmental hazards;
- ✓ Being autonomous;
- ✓ Having a good mileage (a minimum range between charges of at least 50 miles when loaded with two 166-pound occupants and operated at a constant 45 kmph);
- ✓ Having a quick charging time (the battery charger shall be capable of recharging the main propulsion battery to a state of full charge from any possible state of discharge in less than 12 hours);
- ✓ Having acceleration of 10-15 seconds for the speed range of 0 to 100 km/h;
- ✓ Being able to be driven up a 5 to 10 percent ramp at the legal speed under full load condition (a minimum payload of 400 pounds).

Technical Requirements of EV Drive

- ✓ High torque at low speeds;
- ✓ High torque/power to size ratio;
- ✓ Constant power in wide speed range;
- ✓ High efficiency;
- ✓ High dynamic response (fast torque and speed response);
- ✓ Accurate electronic controllability;
- ✓ Robustness and reliability of the motor and its drive;
- ✓ Low Electro Magnetic Interface (EMI) noise susceptibility
- ✓ Reasonable cost of production.

Various types of Electric Motors used in Electric Vehicles

1. DC Motor
2. Brushless DC Motor
3. Permanent Magnet Synchronous Motor (PMSM)
4. Three Phase AC Induction Motors
5. Switched Reluctance Motors (SRM)



Brushless DC Motor

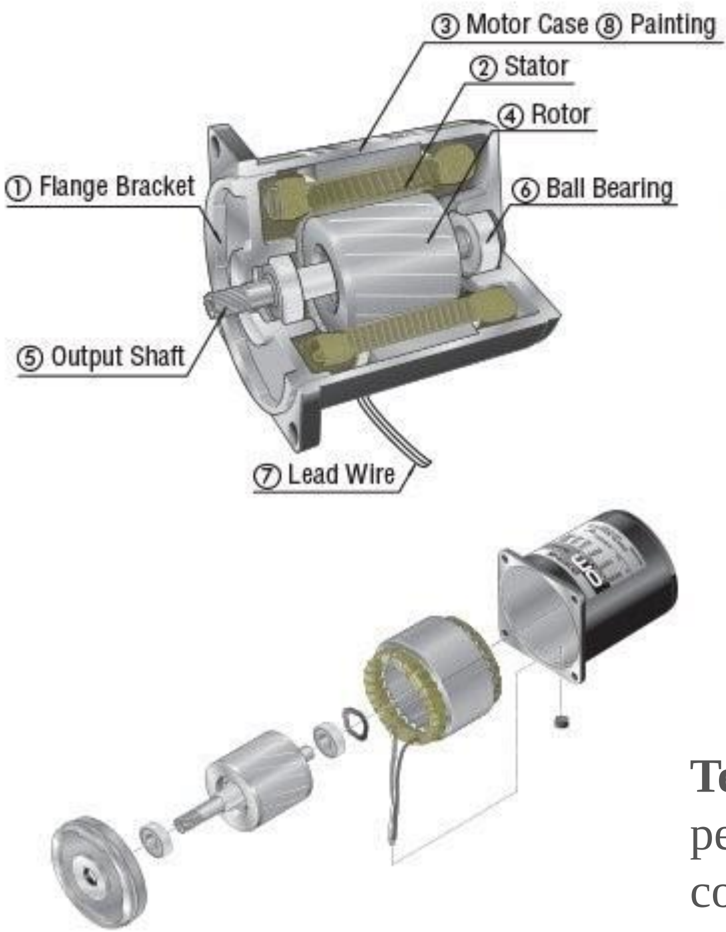
BLDC out-runner type

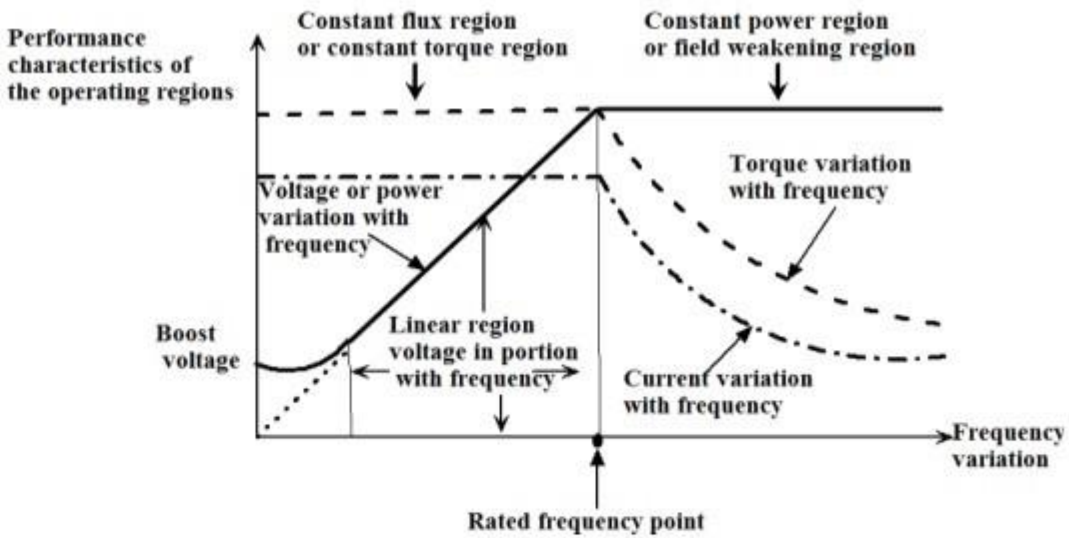
It is similar to DC motors with Permanent Magnets. It is called brushless because it does not have the commutator and brush arrangement.

The commutation is done electronically in this motor because of this BLDC motors are maintenance free. BLDC motors have traction characteristics like high starting torque, high efficiency around 95-98%, etc. BLDC motors are suitable for high power density design approach.

BLDC in-runner type

Induction Motor





Tesla Model S is the best example to prove the high performance capability of **induction motors** compared to its counterparts

But this characteristic can be altered by using various control techniques like FOC or v/f methods. Squirrel cage induction motors have a long life due to less maintenance. Induction motors can be designed up to an efficiency of 92-95%.

The **drawback of an induction motor is that it requires complex inverter circuit and control of the motor is difficult**

Permanent Magnet Synchronous motor

- ✓ This motor is also **similar to BLDC motor which has permanent magnets on the rotor**. Similar to BLDC motors these motors also have traction characteristics like high power density and high efficiency. The difference is that PMSM has sinusoidal back EMF whereas BLDC has trapezoidal back EMF.
- ✓ Permanent Magnet Synchronous motors are available for higher power ratings. PMSM is the best choice for high performance applications like cars, buses.

Permanent Magnet Synchronous motor of Toyota Prius

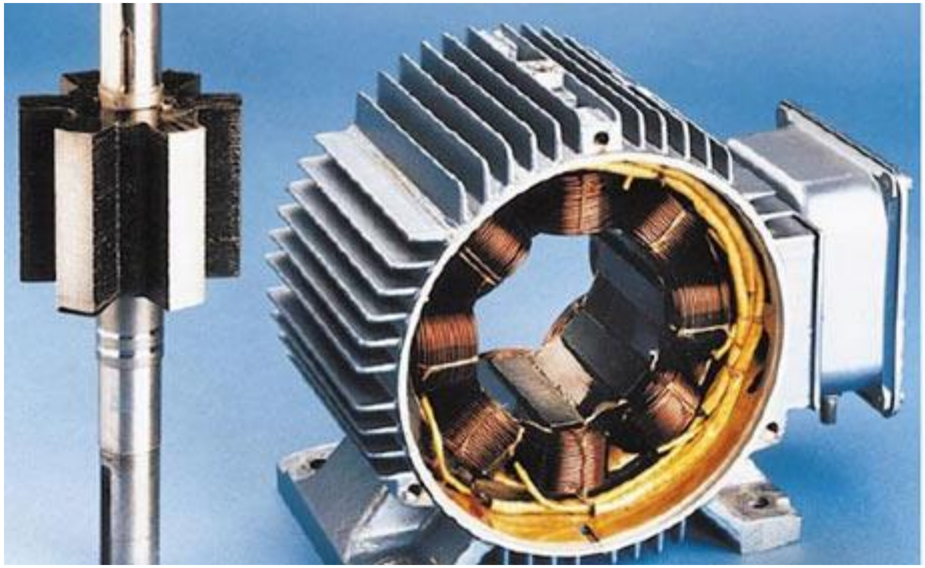
Despite the high cost, PMSM is providing stiff competition to induction motors due to increased efficiency than the latter. PMSM is also costlier than BLDC motors. **Most of the automotive manufacturers use PMSM motors for their hybrid and electric vehicles**

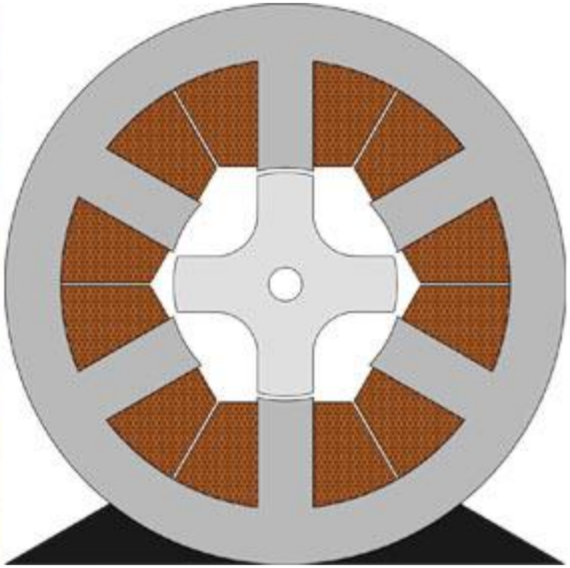
Toyota Prius, Chevrolet Bolt EV, Ford Focus Electric, zero motorcycles S/SR, Nissan Leaf, Hinda Accord, BMW i3, etc use PMSM motor for propulsion.

Switched Reluctance Motor

Switched Reluctance Motors is a category of variable reluctance motor with double saliency. Switched Reluctance motors are simple in construction and robust. **The rotor of the SRM is a piece of laminated steel with no windings or permanent magnets on it**.

This makes the inertia of the rotor less which helps in high acceleration. The robust nature of SRM makes it suitable for the high speed application. SRM also offers high power density which are some required characteristics of Electric Vehicles. Since the heat generated is mostly confined to the stator, it is easier to cool the motor.





The **biggest drawback of the SRM is the complexity in control and increase in the switching circuit**. It also has some noise issues. Once SRM enters the commercial market, it can replace the PMSM and Induction motors in the future.

Summary of Motor Selection

For selecting the appropriate **electric vehicle motors**, one has to first list down the requirements of the performance that the vehicle has to meet, the operating conditions and the cost associated with it.

For example, light duty vehicle and two-wheeler applications which requires less performance (mostly less than 4 kW) at a low cost, it is good to go with BLDC Hub motors. For three-wheelers and two-wheelers, it is also good to choose BLDC motors with or without an external gear system.

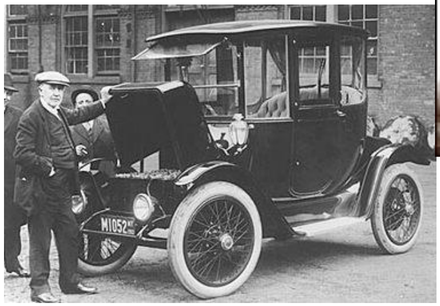
For high power applications like performance cars, buses, trucks the ideal motor choice would be PMSM or Induction motors.

Once the synchronous reluctance motor and switched reluctance motor are made cost effective as PMSM or Induction motors, then one can have more options of motor types for electric vehicle application.

History of Electric Vehicles

1891 William Morrison of Des Moines the first successful electric automotive

1907-1939 Detroit Electric successful electric car co.



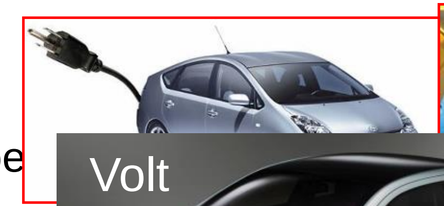
Thomas Edison - 1912

1974 Vanguard Sebring CitiCar

1990 Cal. Zero Emission Vehicle (ZEV) Mandate. 2% by 1998, 10% by 2003

1990-2000 few thousand electric vehicles

2002 GM and DaimlerChrysler sued CARB and ZEV mandate was weakened

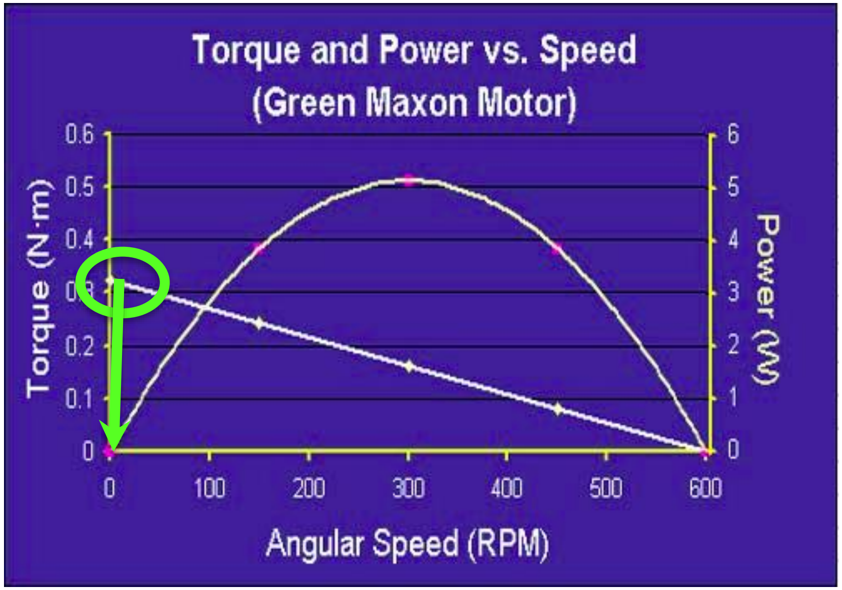


2006 PHEVs, retrofits: Prius, Escape

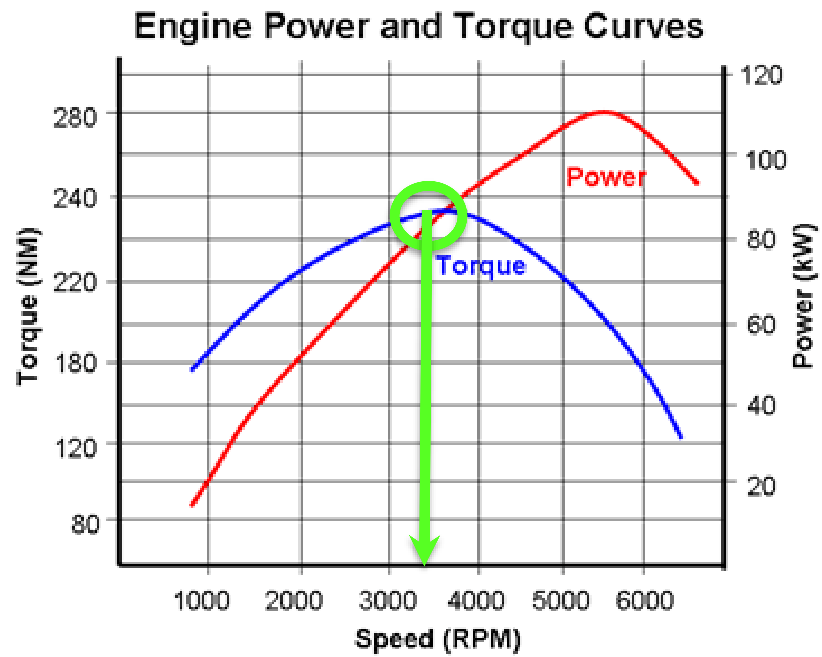
2010 GM Volt, other manufacturers

Performance: Electric motor generates maximum torque at lowest speeds

Electric motor



Internal combustion engine



Definition of Electric Vehicles

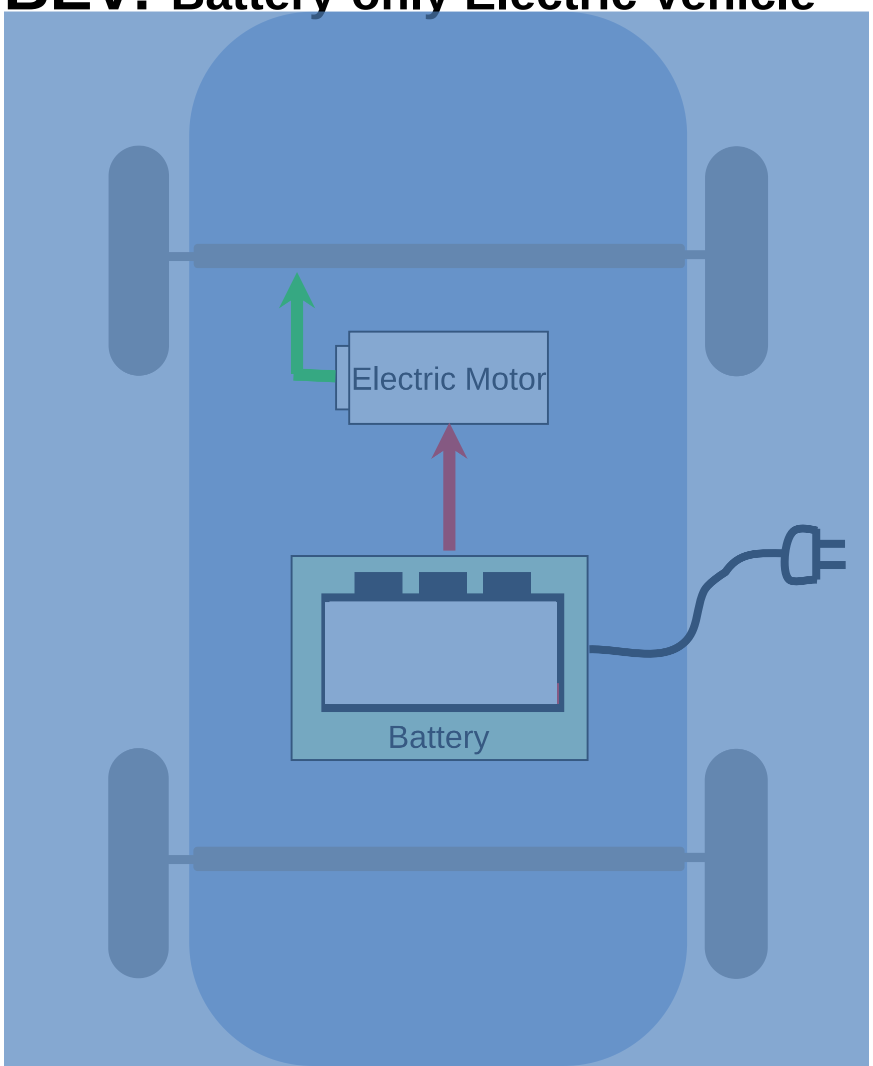
PEV: Plug-in Electric Vehicle

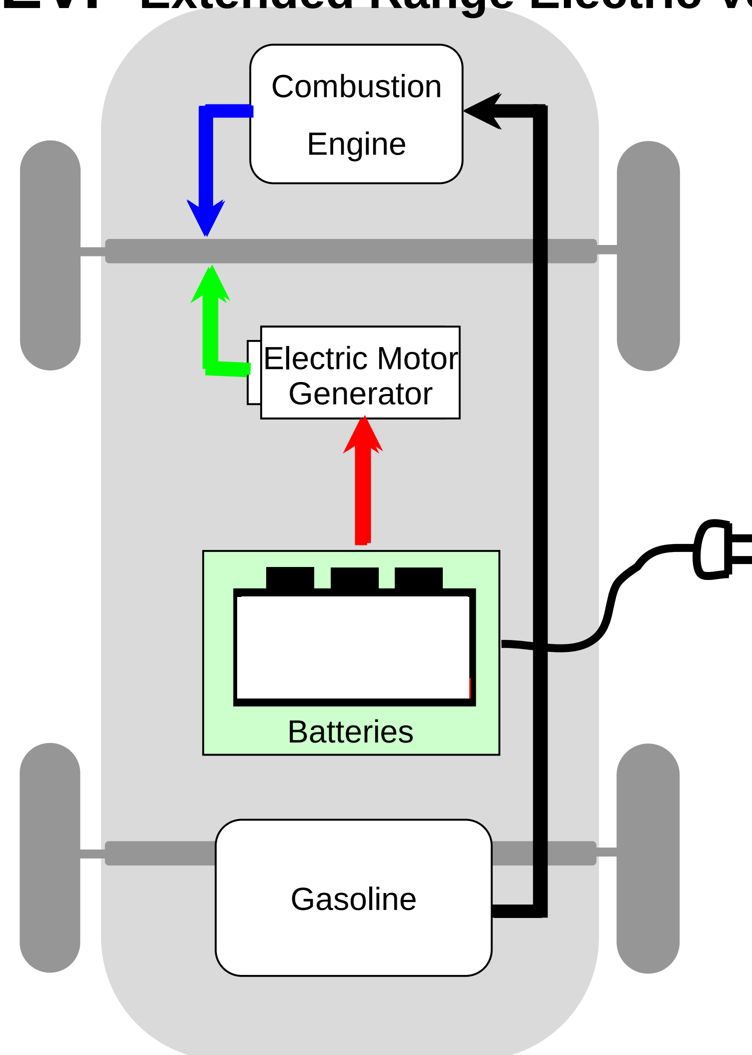
EV: Electric Vehicle

BEV: Battery-only Electric Vehicle

PHEV: Plug-in Hybrid Electric Vehicle

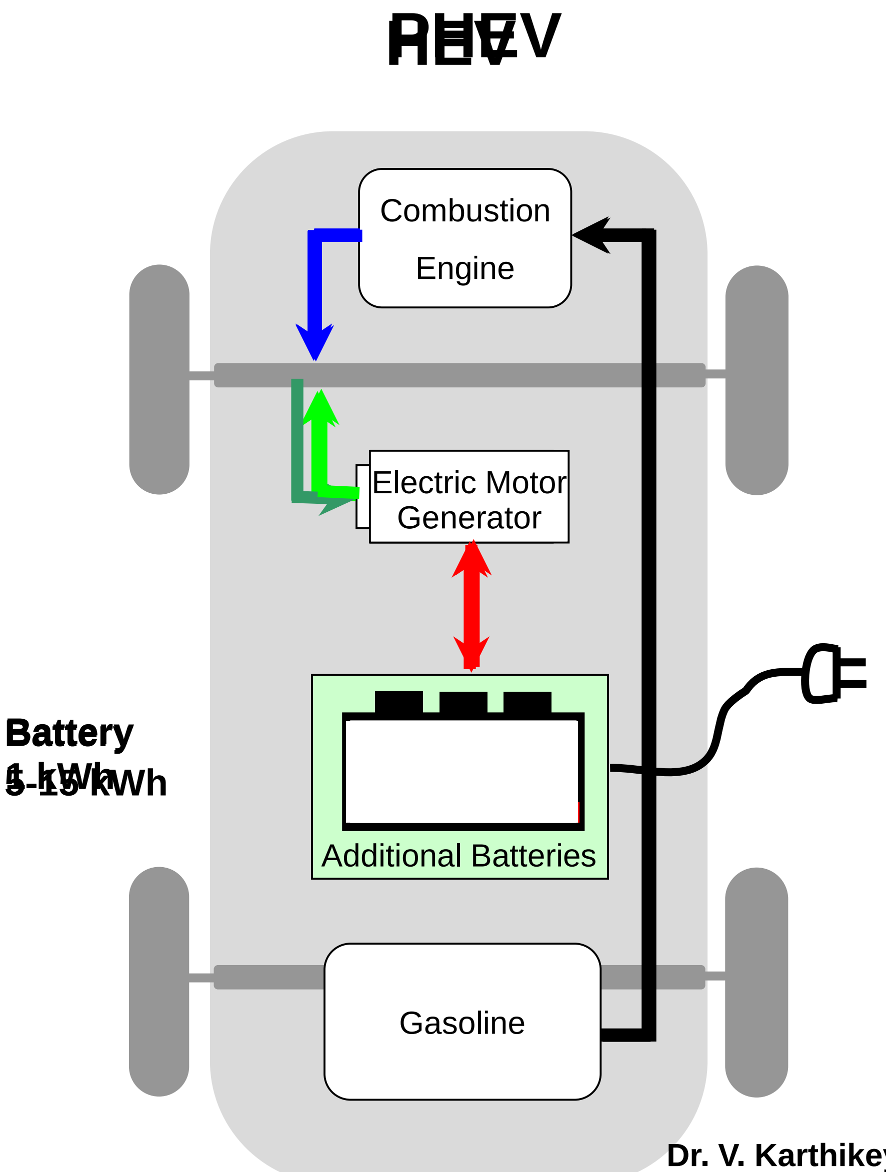
EREV: Extended Range Electric Vehicle





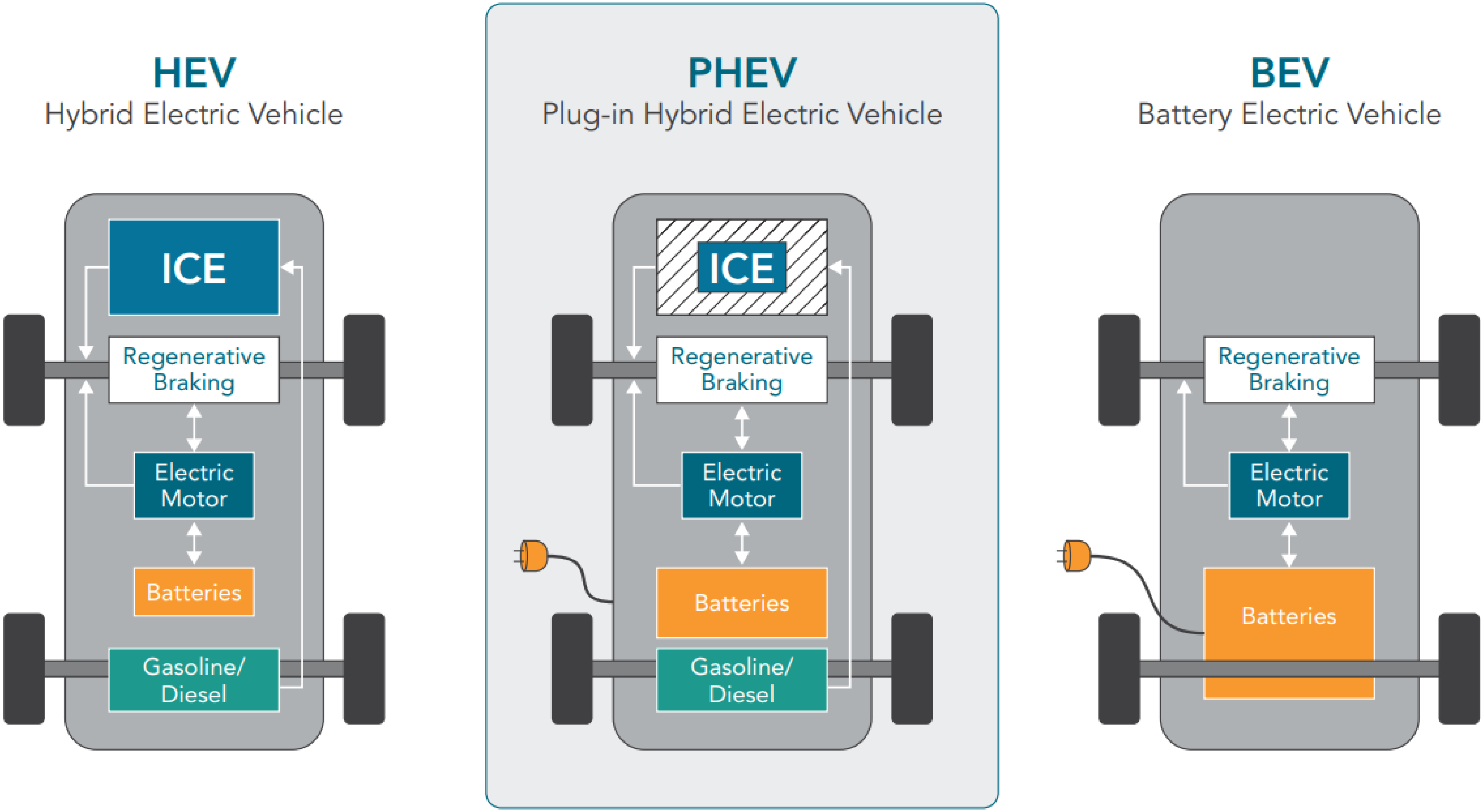
How Does a PHEV or EREV Work?

How Does a PHEV or EREV Work?



- PHEVs overcome the range problem of BEVs
- Electric-only range vary with battery size
  - PHEV20 = 35 km range
  - PHEV40 = 65 km range
- PHEVs well suited for our daily driving patterns
  - 50% of all daily drives <40 km
  - 80% of all daily drives <80 km
  - Average daily driving=55 km

Classification of EVs



What is HEV...?

- A hybrid car is any car that uses both electricity and fuel injection in order to run.

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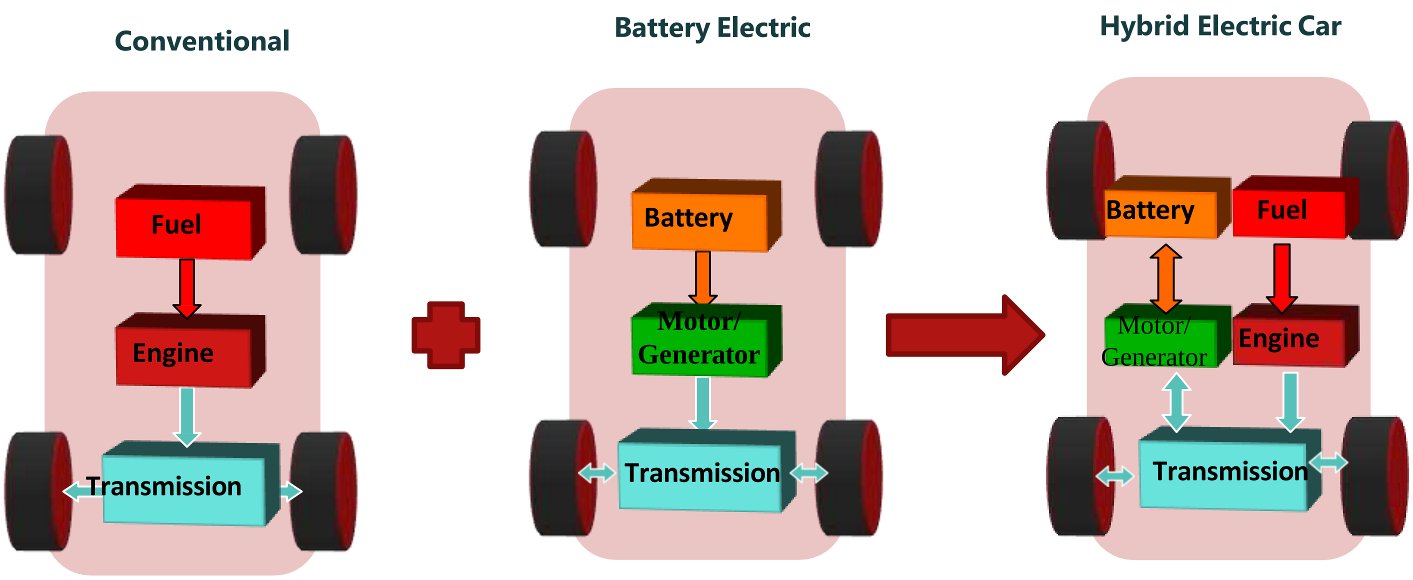
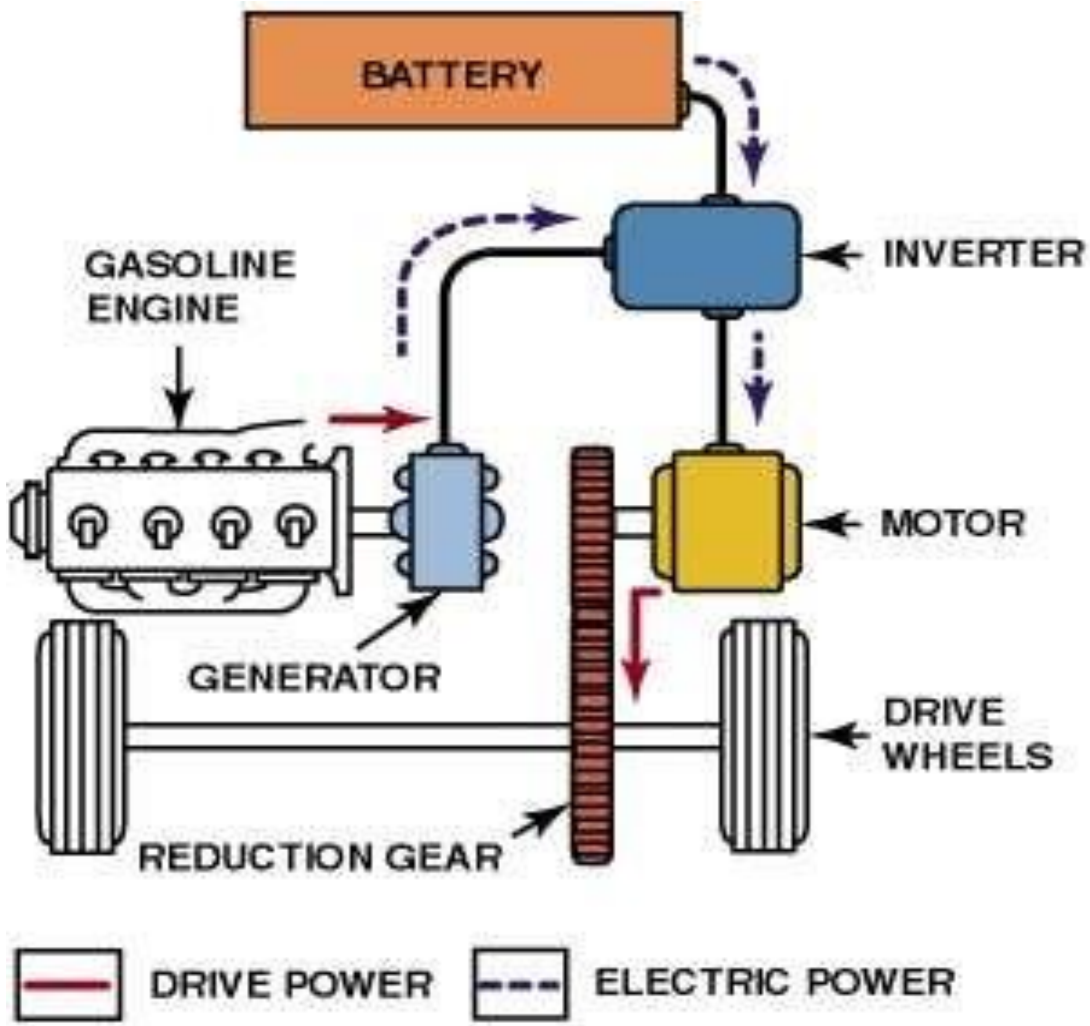


Types of Hybrid

1. Series hybrid

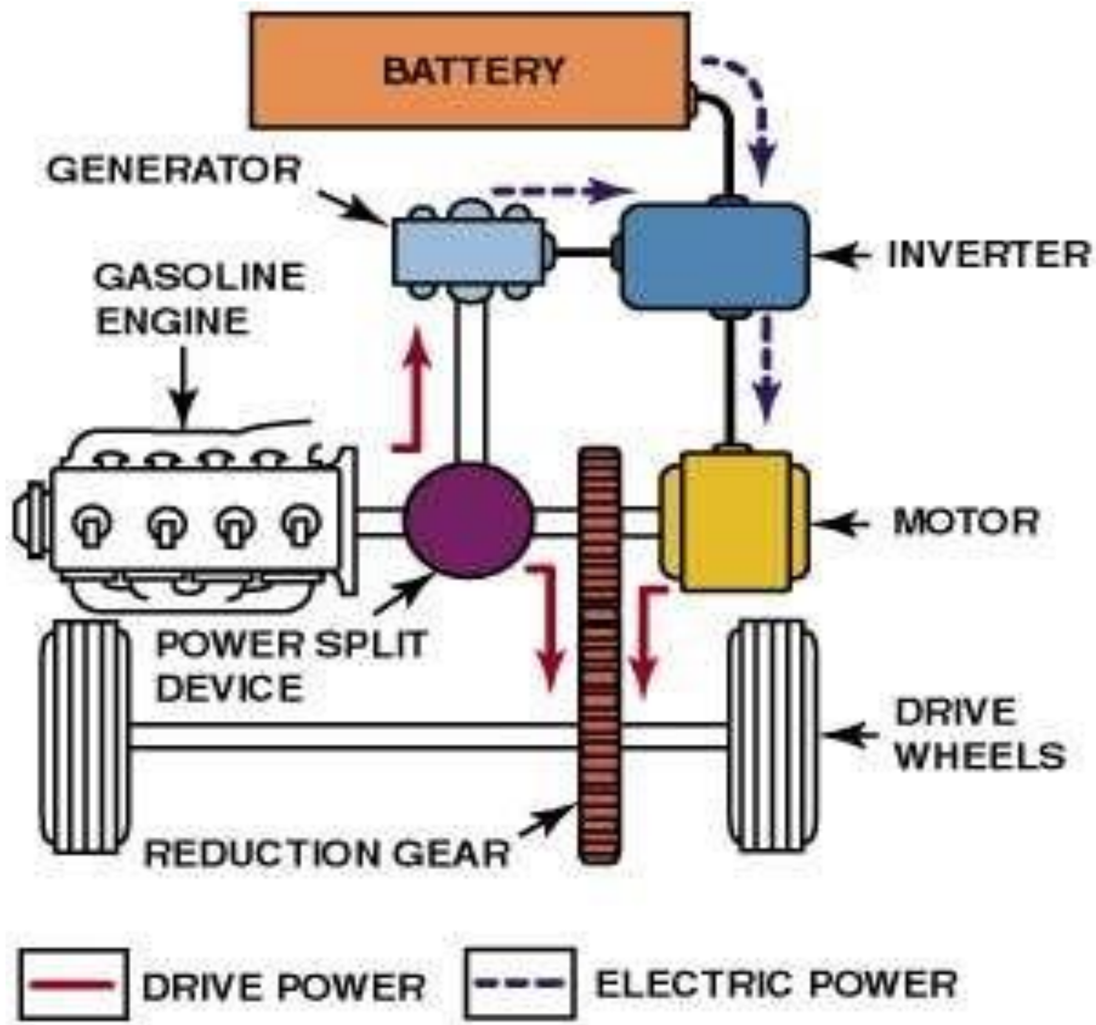
- The fuel tank goes to the engine, but the engine turns a generator.
- Then the generator can either charge the batteries or power an electric motor that drives the transmission.
- The gasoline engine does not directly power the car.



Types of Hybrid

2. Parallel hybrid

- ✓ It has a fuel tank that supplies gas to the engine like a regular car.
- ✓ It also has a set of batteries that run an electric motor.
- ✓ Both the engine and electric motor can turn the transmission at the same time.



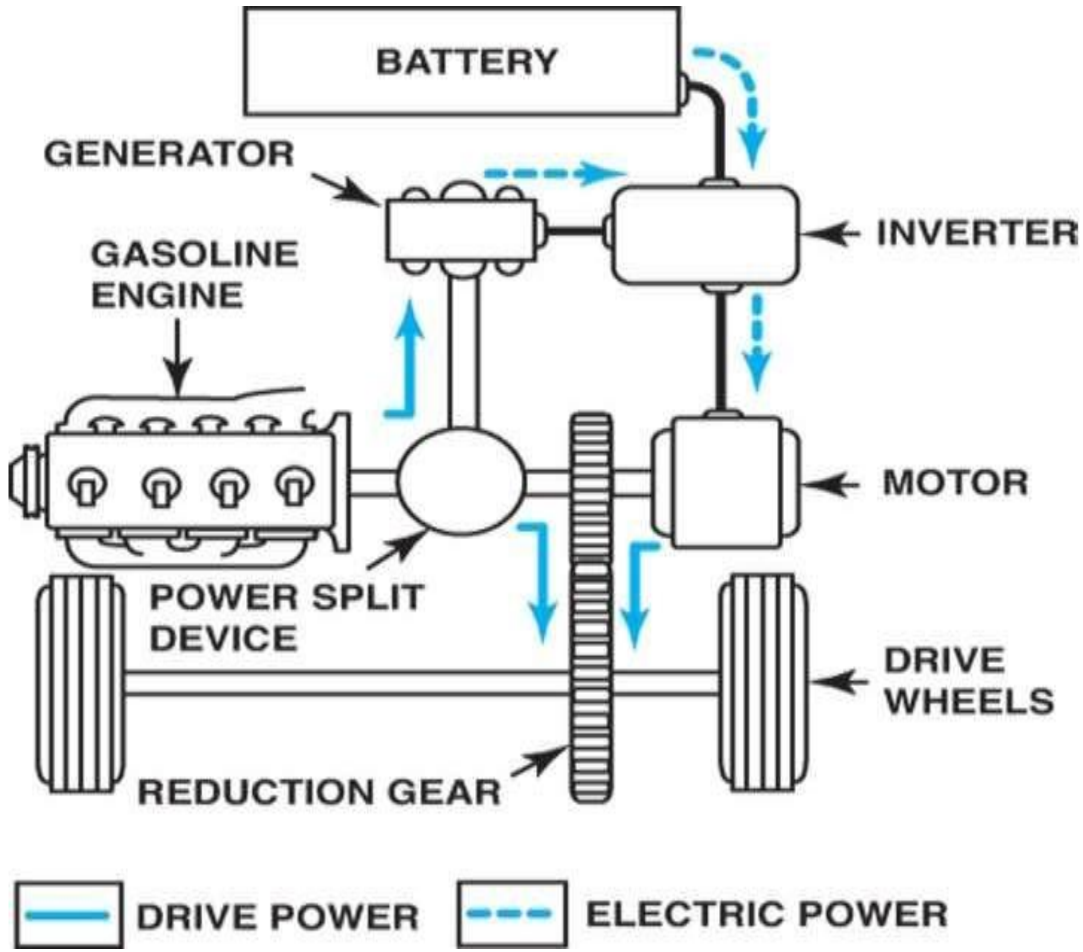
Types of Hybrid

3. Series - Parallel hybrid

Series-Parallel type also called Power-split hybrids.

More beneficial then above hybrid.

Most of the latest vehicle based on this hybrid.



Summary of Hybrid

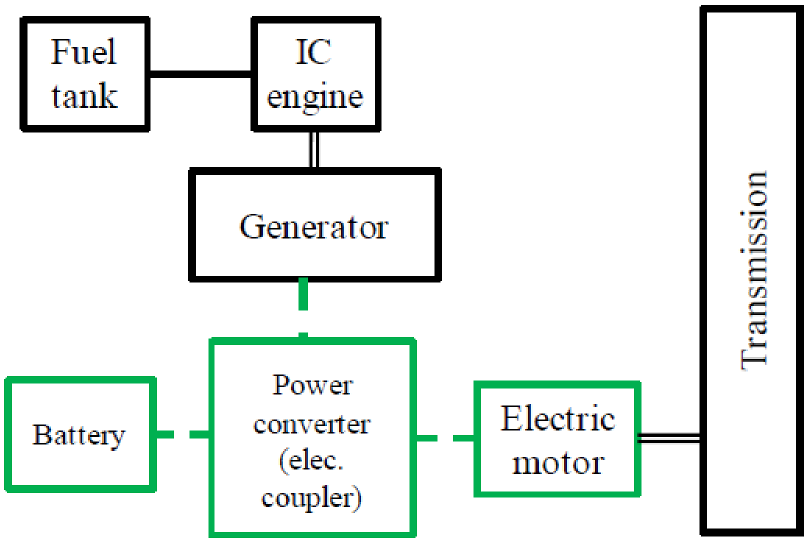


Figure 4a: Series hybrid [1]

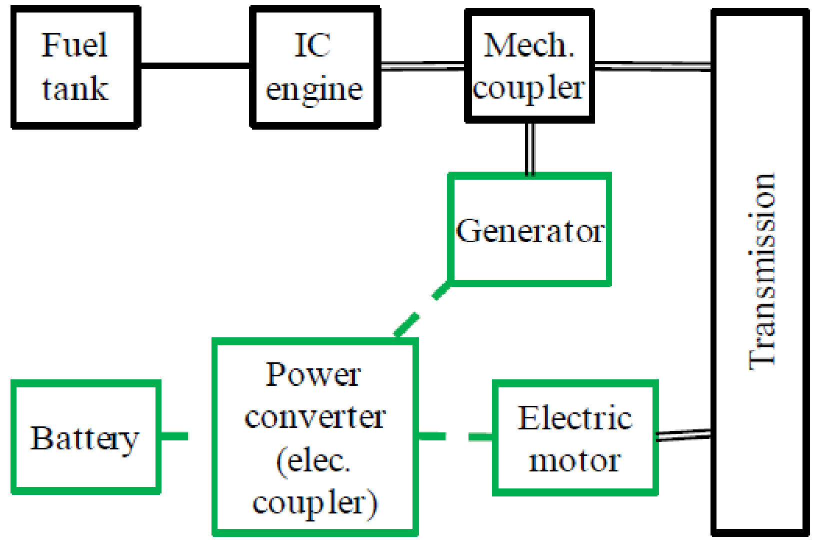


Figure 4b: Series-Parallel hybrid [1]

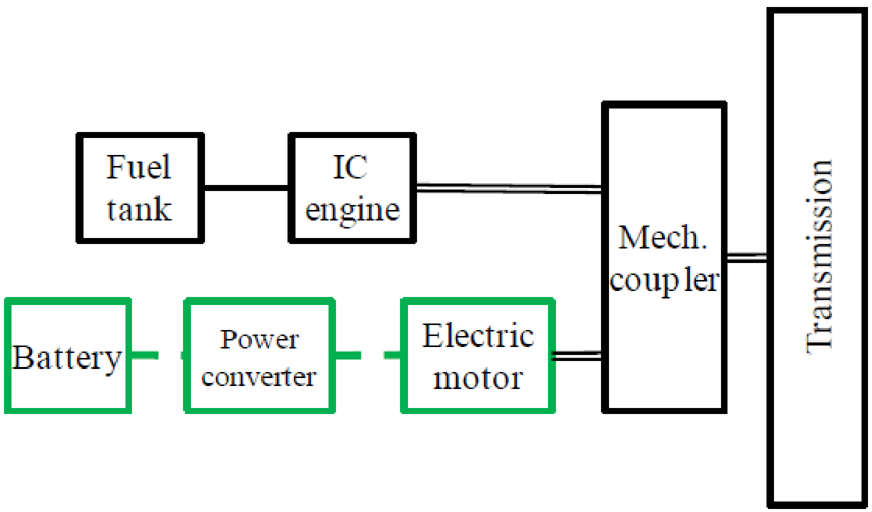


Figure 4c: Parallel hybrid [1]

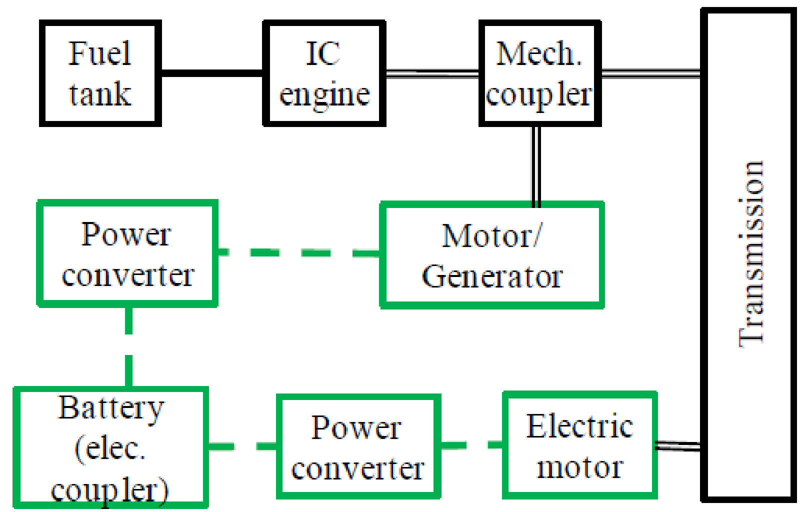


Figure 4d: Complex hybrid [1]

Parts of HEV vehicle

1. Engine

It's much same as other vehicles engine, but the size of hybrid electric vehicle

engine is small and it's more fuel efficient. There are two types of engine, mostly used in HEV vehicles are i) Petrel Engine and ii) Diesel Engine

2. Battery

It stores the energy generated from gasoline engine or during regenerative braking, from the electric motor. There are 3 types of batteries used in HEV,

- ✓ Lead Acid(2.2 volt)
- ✓ Nickel Cadmium (1.2 volt)
- ✓ Lithium-ion(3.7 volt

3. Electrical Motor

It's power the vehicle at low speed and assist the gasoline engine when additional power is needed. Most of the electric machines used in hybrid vehicles are brushless DC motors (BLDC).

4. Controller

The controller is used to charge the battery or to supply the power to electric motor.

- ✓ Converts battery DC into chopped DC power
- ✓ Can chop the amplitude and frequency
- ✓ Power can be converted using low voltage input signal 4-20 mA or 0-5V

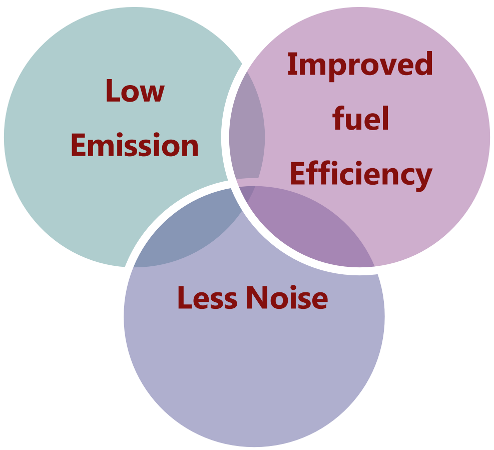
5. Generator

It converts mechanical energy from engine into electrical energy, which can be used by electric motor stored in the battery. It's also used to start the gasoline engine instantly.

HEV benefits and drawbacks

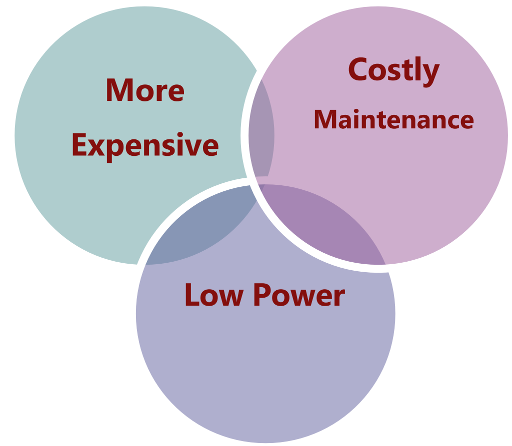
Merits of HEV

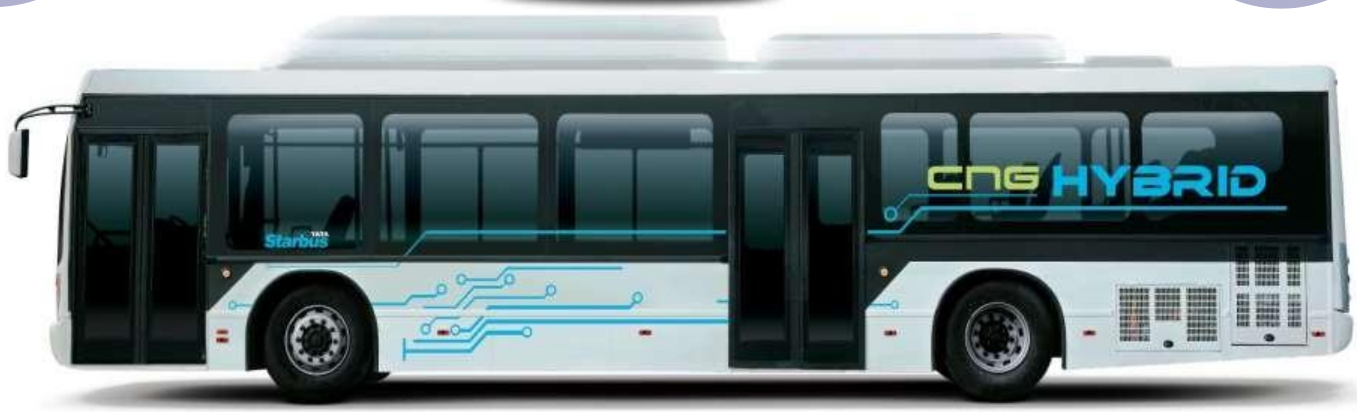
- ✓ Savings
- ✓ Low Emissions
- ✓ Reduced Noise Pollution
- ✓ Low Maintenance
- ✓ Safe to Drive



De-Merits of HEV

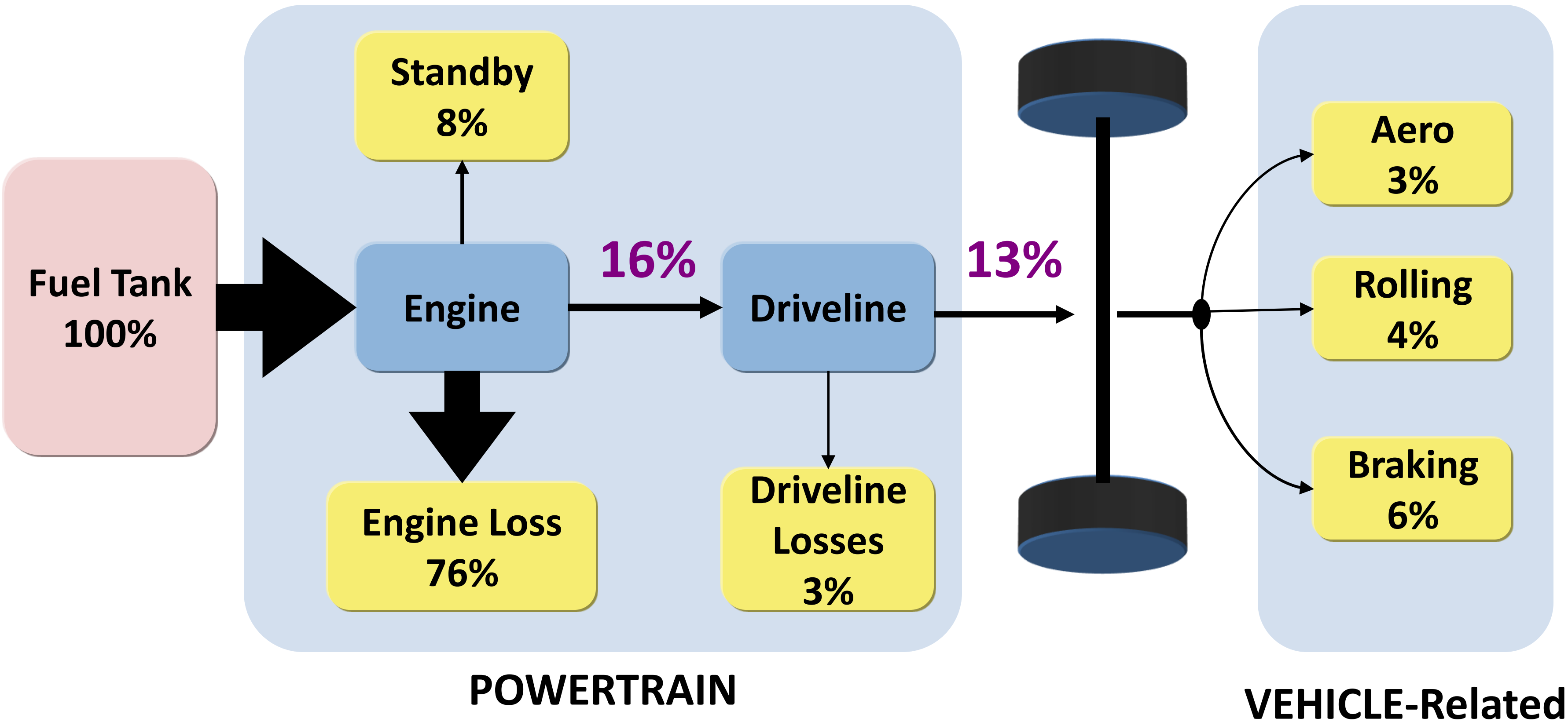
- ✓ Hybrids are more expensive than non-hybrids.
- ✓ Hybrids (in regards to a car accident) have a much higher risk of exploding because it has a combination of gasoline and ethanol.
- ✓ Sometimes they can be pretty ugly.
- ✓ Parts can be very expensive to repair (between 60 Lakhs to 180 Lakhs)
- ✓ Slower than petrol powered cars.





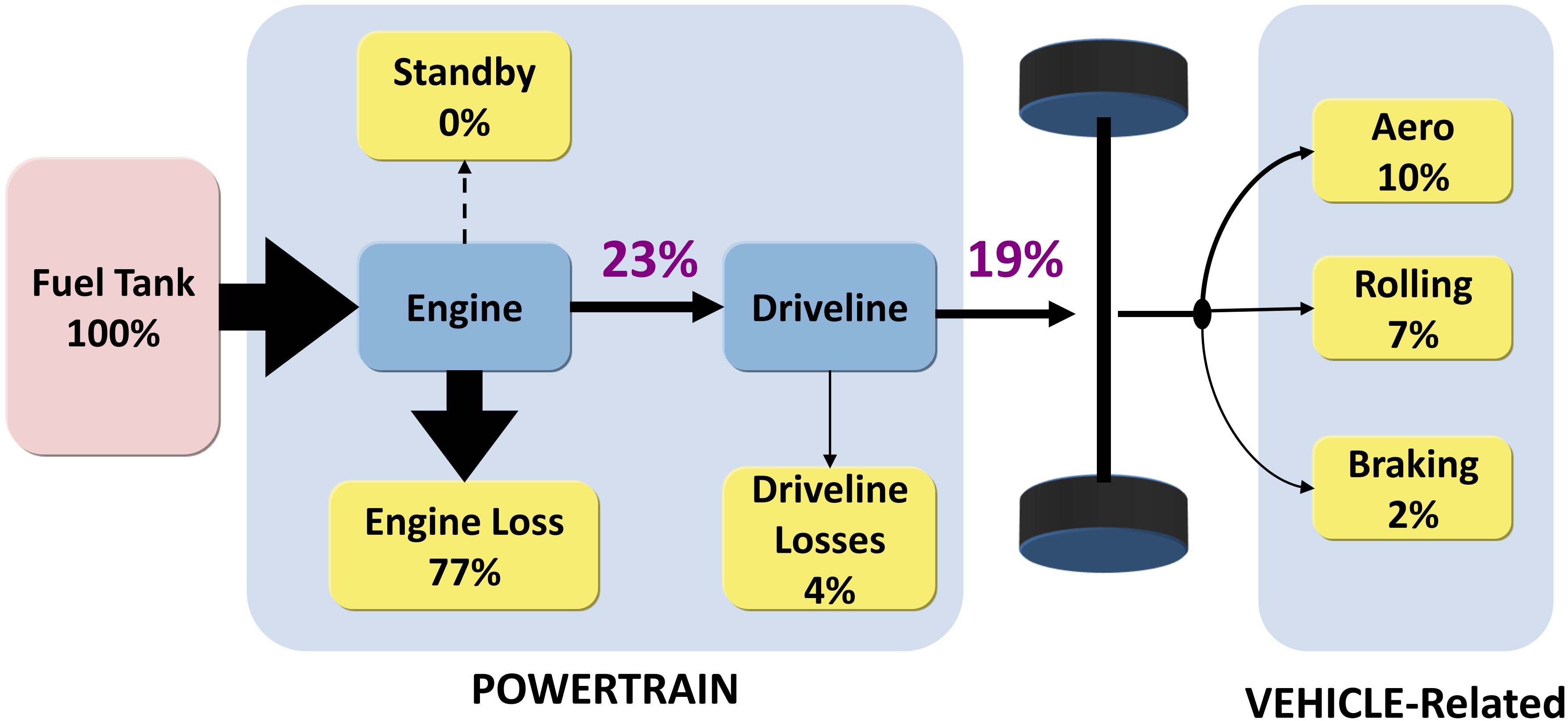
Energy Loss : City Driving

Urban Drive Cycle Energy Balance

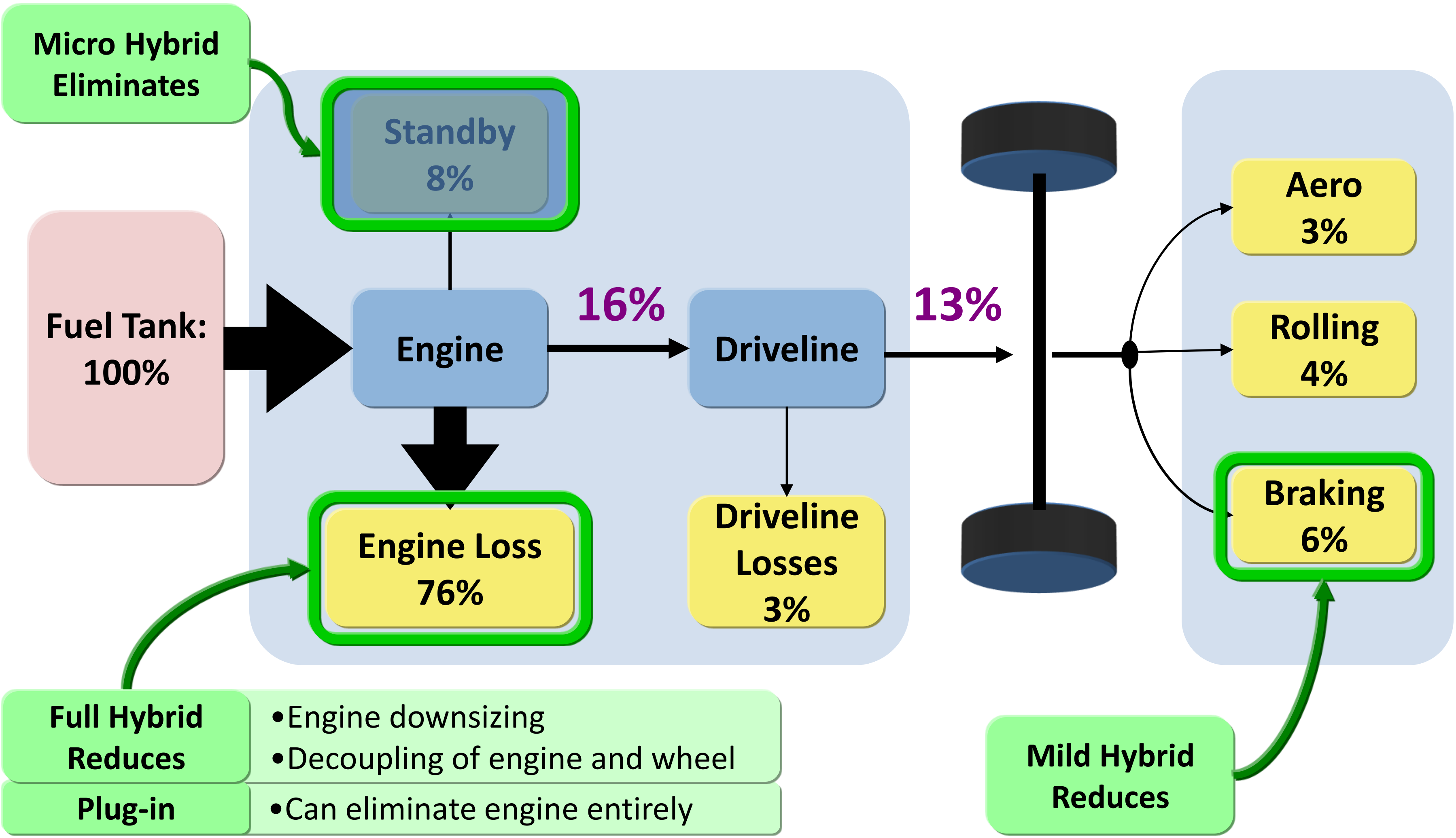


Energy Loss : Highway Driving

High way Drive Cycle Energy Balance

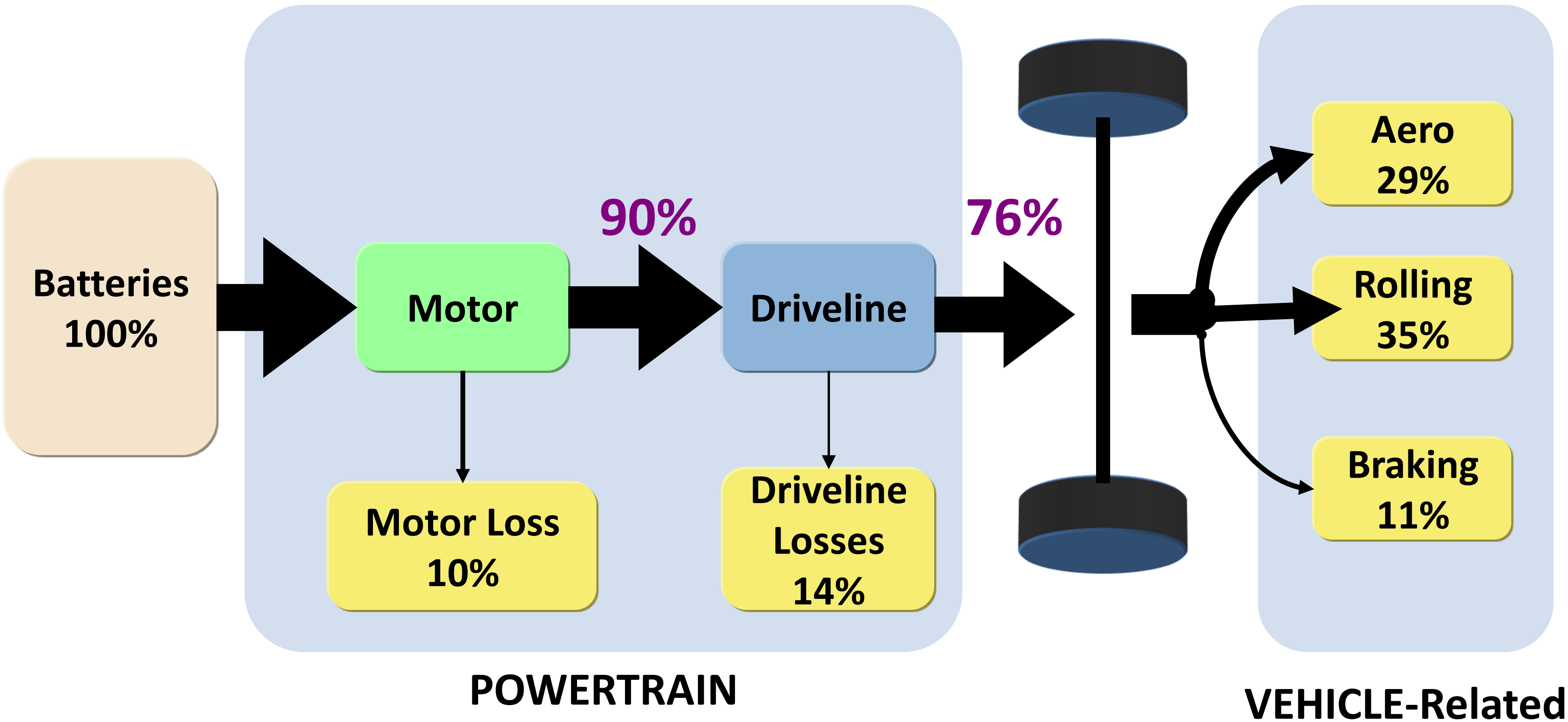


Energy Saving : Hybrid Systems



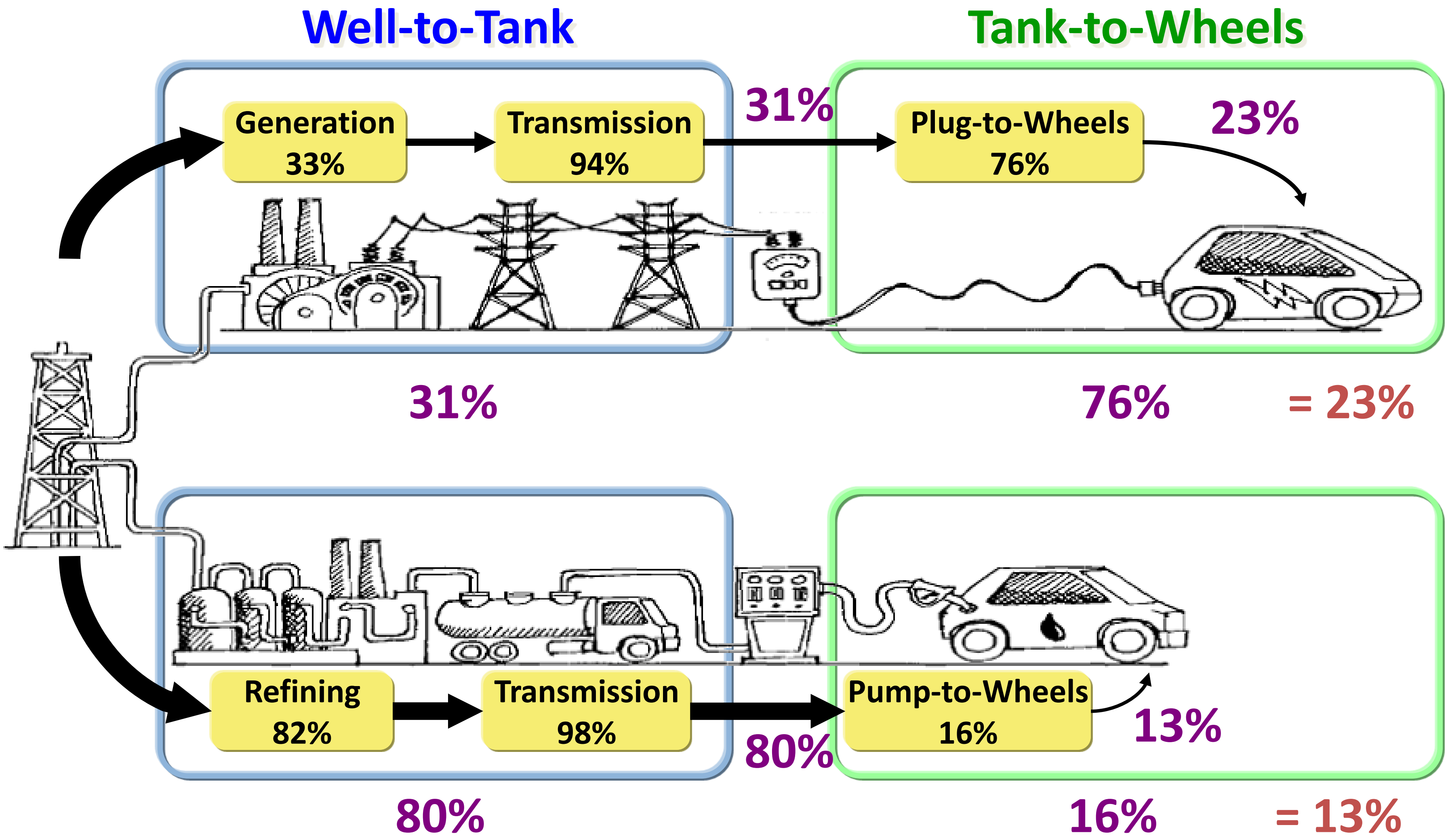
Energy Loss : City Driving – Electric Vehicle

Urban Drive Cycle Energy Balance

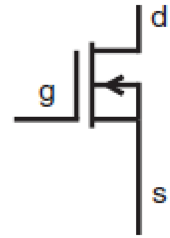
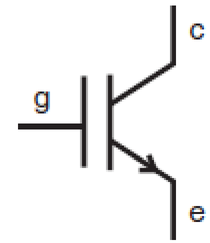


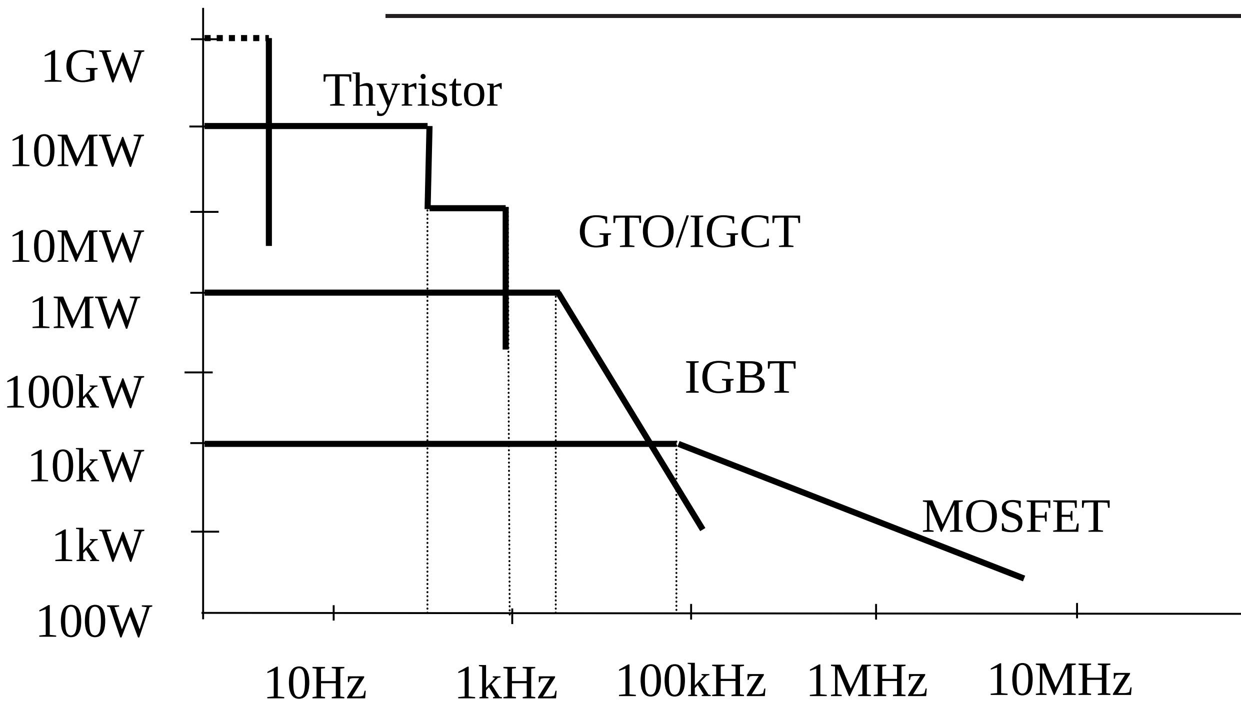
Dr. V. Karthikeyan, Assistant professor

Well-to-Wheels Efficiency

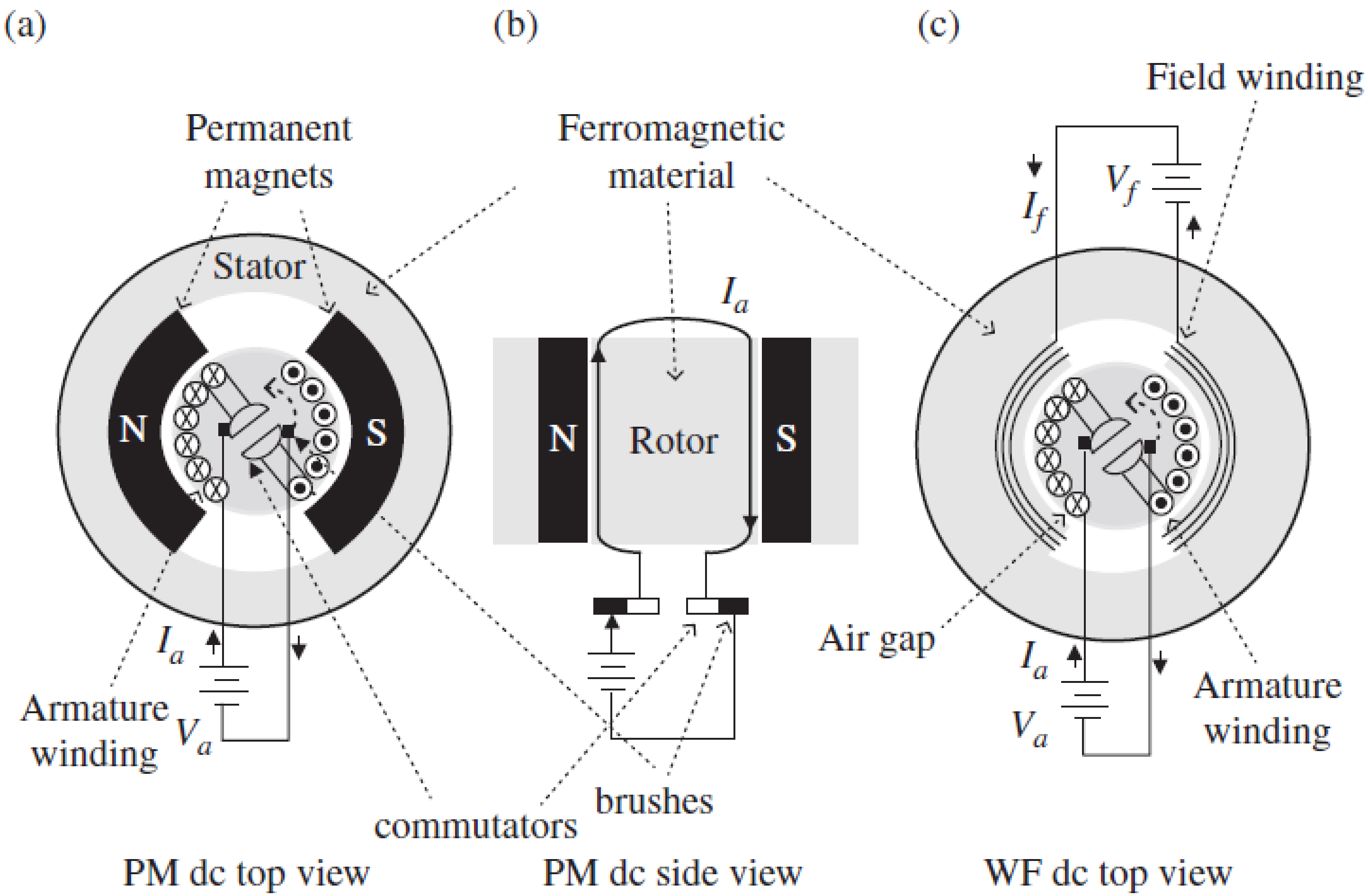


Power Switches: Power Ratings

Type	Thyristor	MOSFET	IGBT
Symbol			
Maximum voltage (V)	4500	1000	1700
Maximum current (A)	4000	50	600
Switching time (μs)	10–25	0.3–0.5	1–4

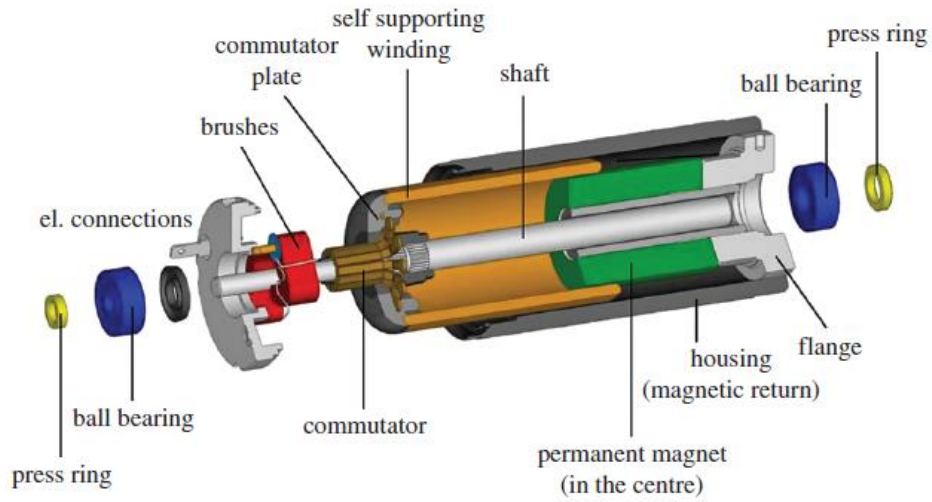


Role of Power Converter : DC Drives



Elementary dc machines.

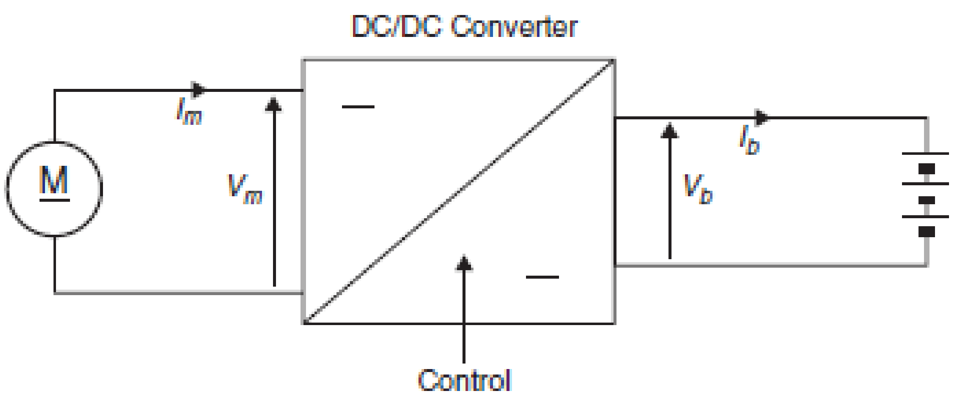
Role of Power Converter : DC Drives



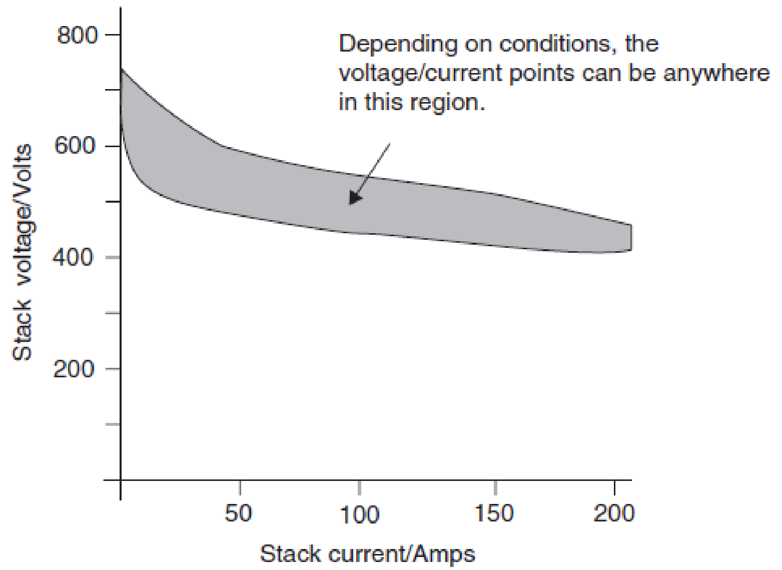
There are two broad classes of dc machine: the **brushed** motor with lifetime limitations, and the **electronically commutated** (EC) dc motor with a significantly greater lifetime.

The EC dc machine is closer in operation to a PM ac motor in that the PMs are located on the rotor and the current-carrying conductors are located on the stator.

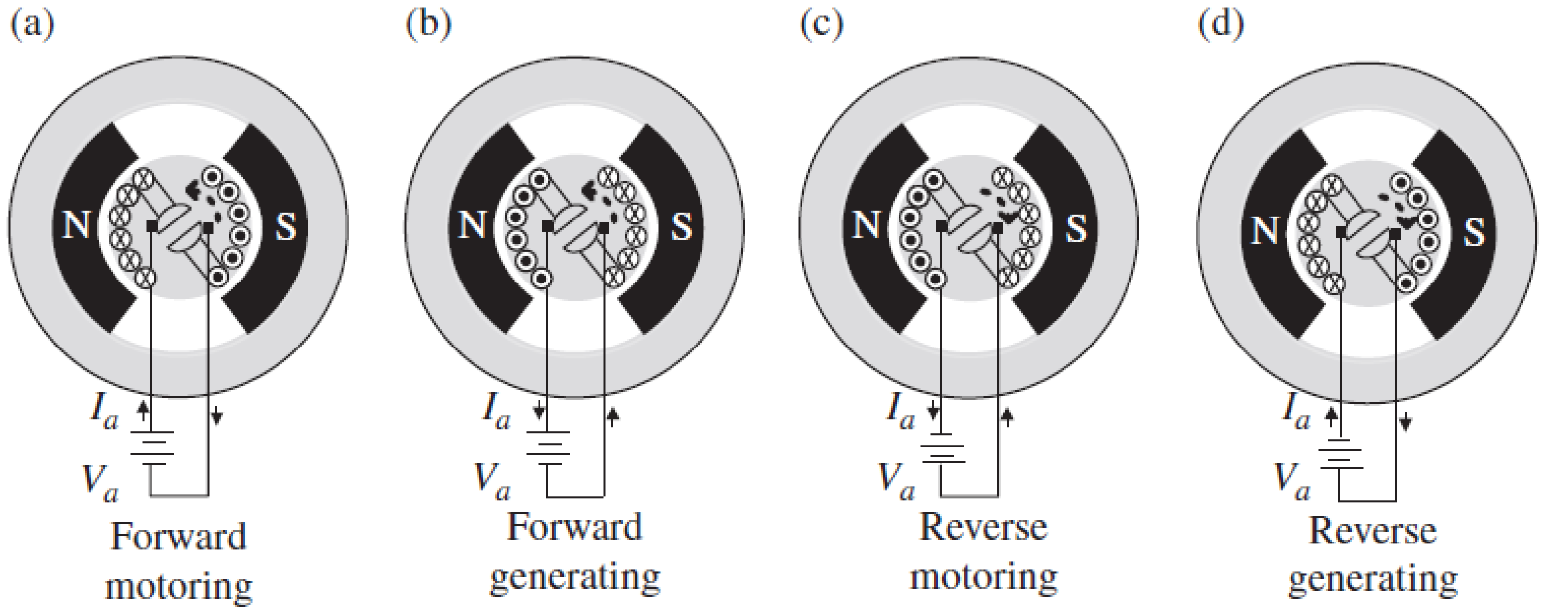
i) **brushed PM dc motor**
ii) **wound-field dc machine**

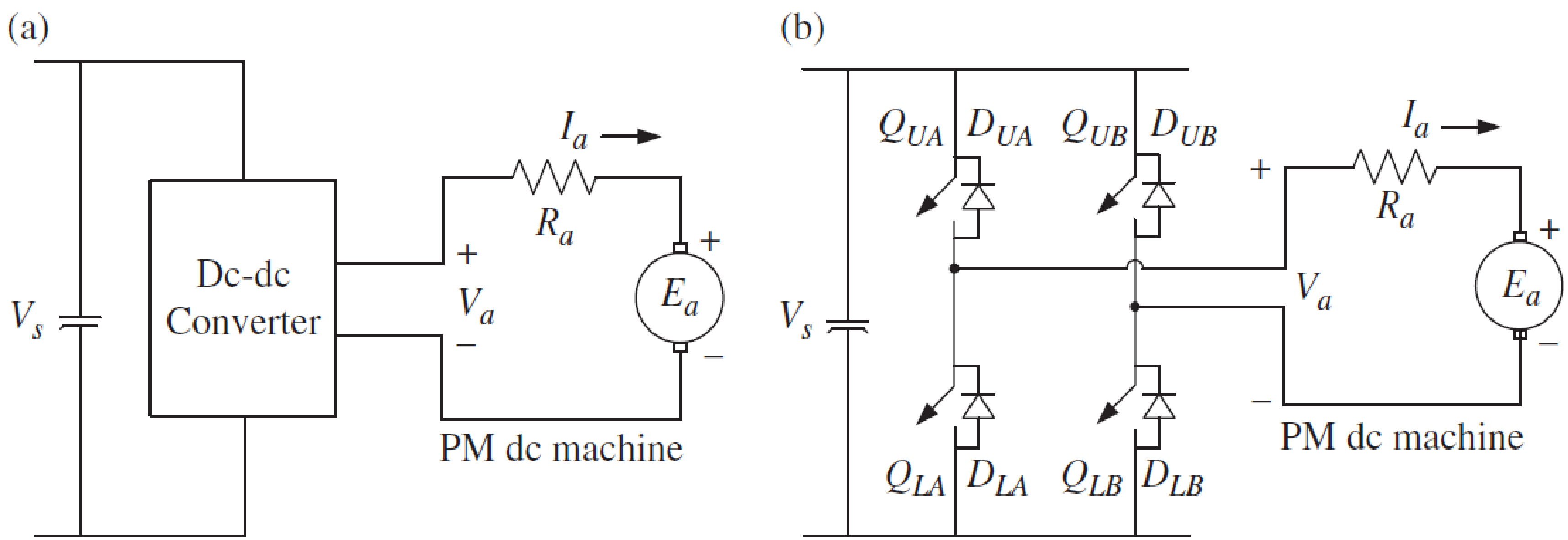


DC Motoring / Regenerative braking of a DC motor

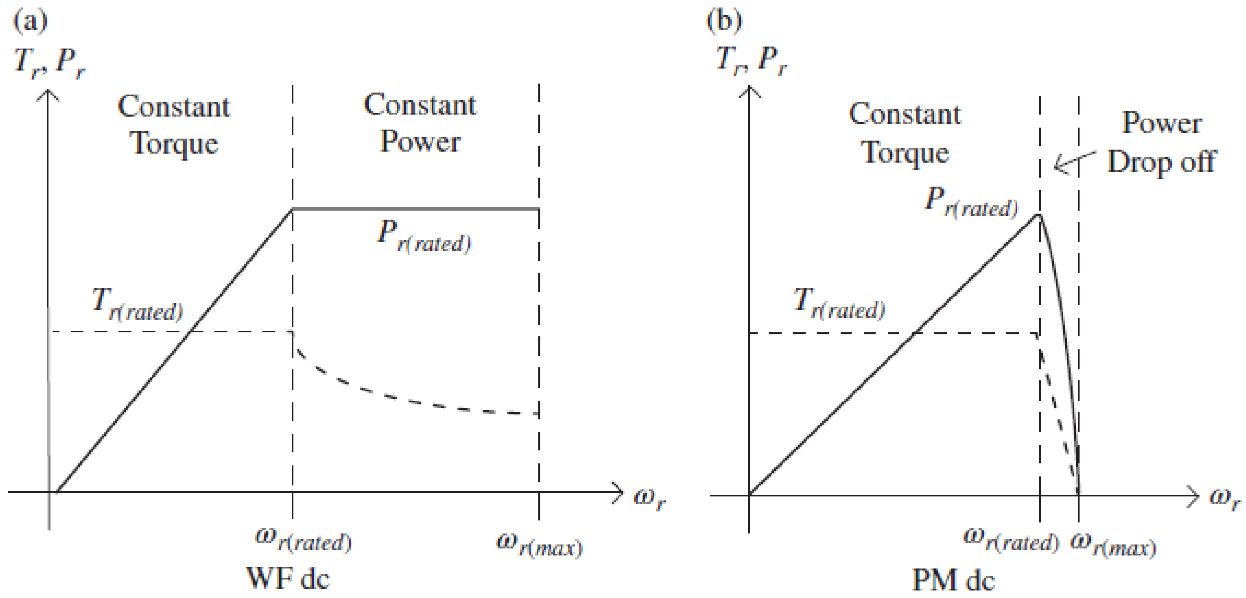


Role of Power Converter : DC Drives





Role of Power Converter : DC Drives



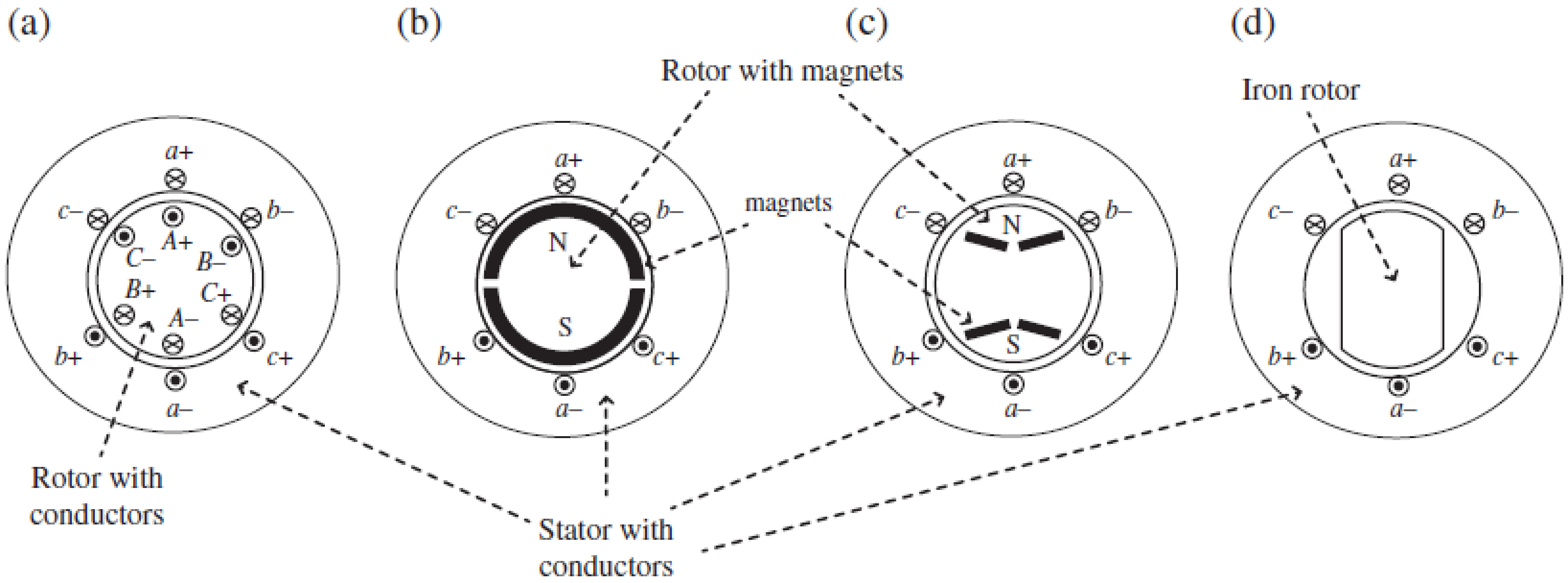
(a) Wound-field (WF) dc and (b) permanent-magnet (PM) dc machine power and torque characteristics.

Power-drop-off mode: In this mode, the machine power and torque are limited, and both tend to zero at the maximum no-load speed of the machine.

It is a serious limitation of the PM dc machine to not have a constant-power or field weakened mode. The machine cannot operate at higher speeds as the machine is constrained to operate with a maximum speed close to the rated speed.

The PM dc machine can be used in single-gear vehicles but requires a variable gearing mechanism similar to that of a conventional internal-combustion engine vehicle in order to operate over the full speed range.

Role of Power Converter : AC Drives



Sketches of (a) induction, (b) surface permanent-magnet, (c) interior permanent-magnet, and (d) reluctance machines.

One of the significant advantages of increasing the pole pairs in a machine is that it runs at a higher electrical frequency for a given mechanical speed, which reduces the machine size and weight. The induction motor used in the 1996 GM EV1 was a four pole machine. The PM motors used in the Nissan Leaf and Toyota hybrids are eight-pole. There are two broad classes of ac machines: **asynchronous** and **synchronous**.

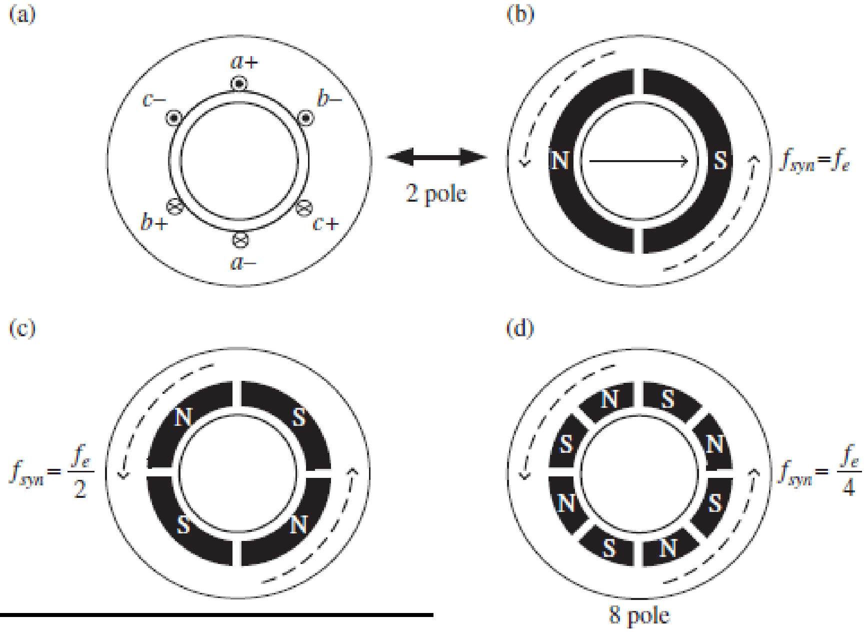
Both types of machine have a similar stator but have different rotor constructions. **squirrel-cage induction motor** invented by Nikola Tesla.

Role of Power Converter : AC Drives

The spinning magnetic field due to Tesla's invention for various magnetic pole counts.

Positive characteristics of a machine earn from one ✓ to two ✓✓. Negative characteristics earn a ✗. A double ✗✗ means that the machine is unsuitable for the automotive powertrain application.

The spinning magnetic field due to Tesla's invention for various magnetic pole counts.



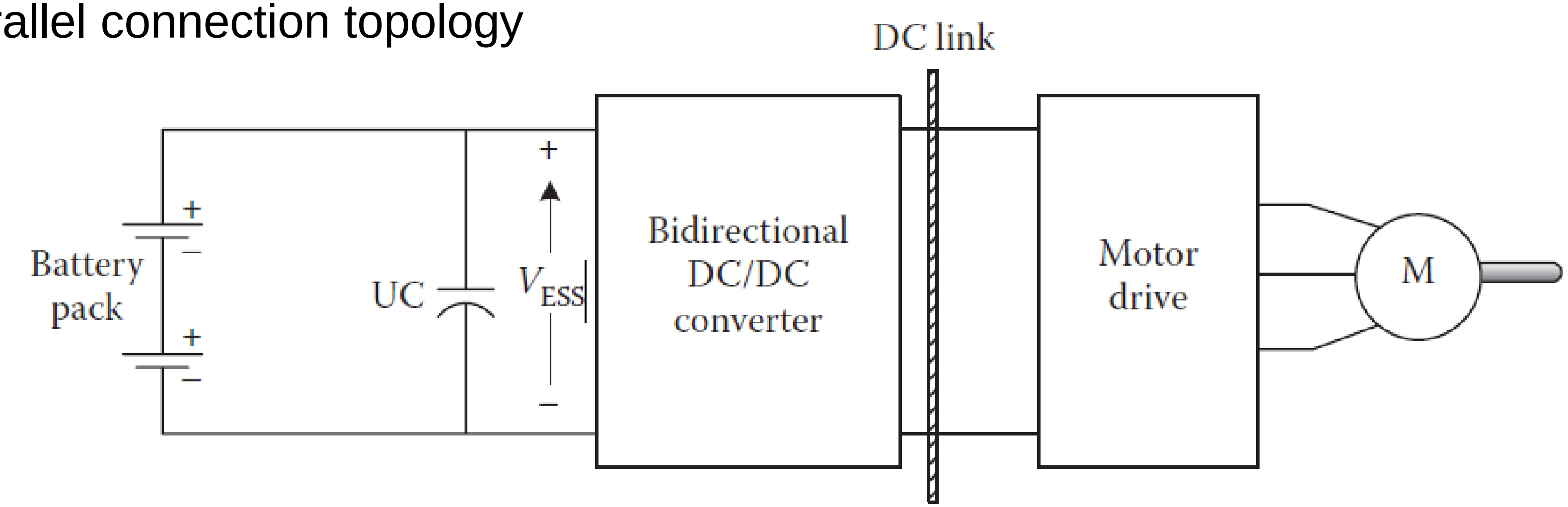
A comparison of various traction machines.

Attribute	ac SPM	ac IPM	ac SC IM	ac RM	dc PM	dc WF
Size	✓✓	✓✓	✓✓	✗✗	✗	✗
Cost	✓	✓✓	✓✓	✓✓	✗	✗
Efficiency	✓✓	✓✓	✓	✓✓	✗	✗
High-speed field weakening	✓✓	✓✓	✓✓	✓	✗✗	✓✓
Rotor cooling	✓✓	✓✓	✗	✓✓	✗	✗
Service and maintenance	✓✓	✓✓	✓✓	✓✓	✗✗	✗✗
Fault tolerance	✗✗	✓	✓✓	✓	✗✗	✓
Automotive powertrain	✗✗	✓✓	✓✓	✗✗	✗✗	✗✗

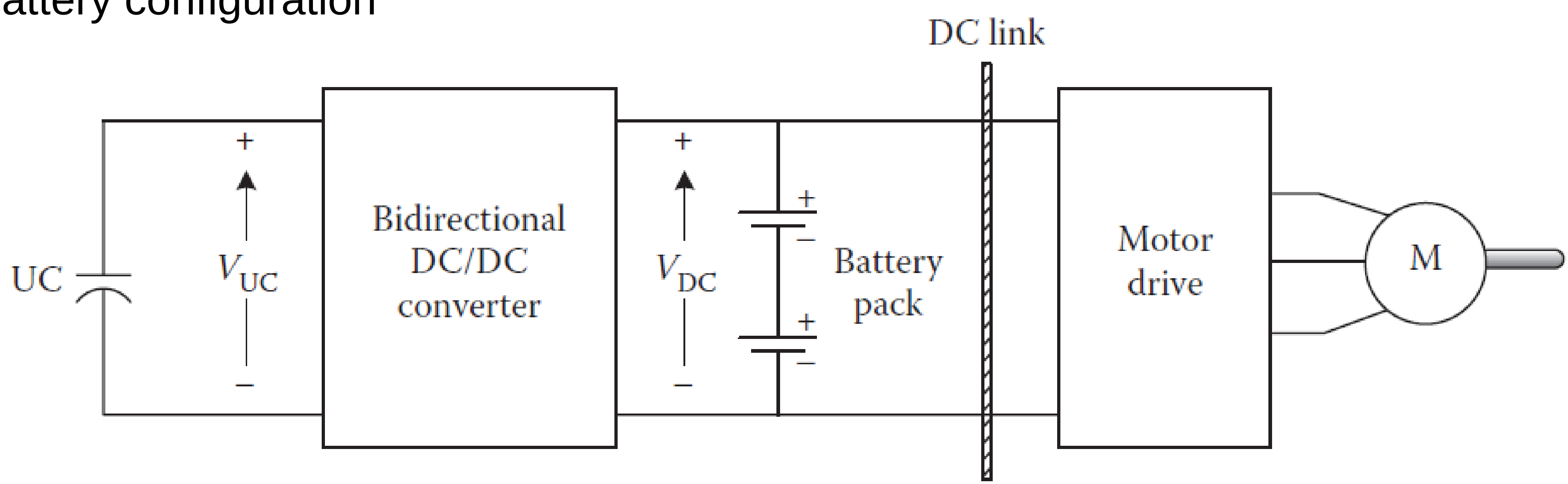
1. Core Losses
   - ✓ Hysteresis Losses
   - ✓ Eddy Current Losses
2. Copper Losses
3. Mechanical Losses
   - ✓ Friction Losses
   - ✓ Windage Losses

Role of Power Converter : AC Drives

Passive parallel connection topology

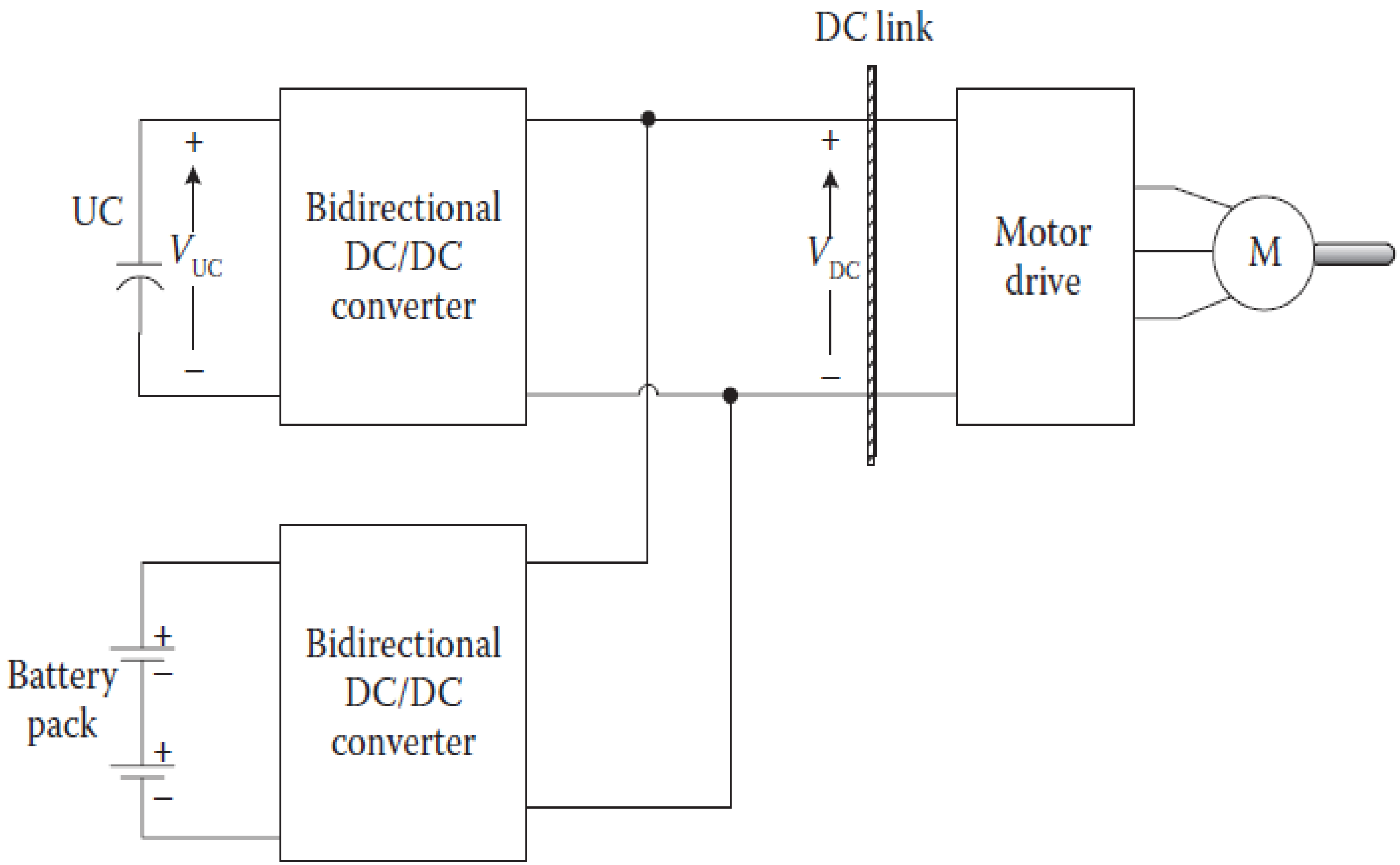


UC/battery configuration



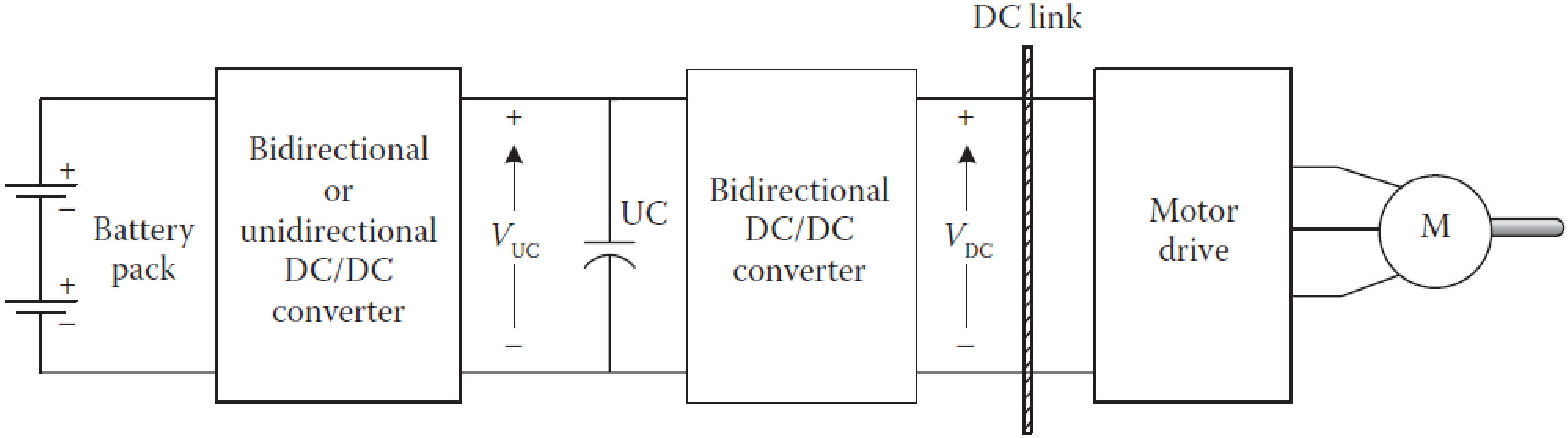
Role of Power Converter : AC Drives

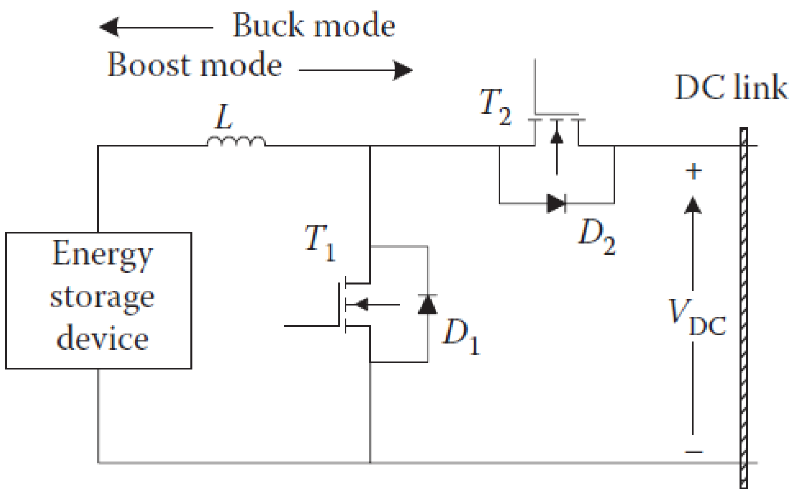
Another representation of the same UC/battery configuration



Role of Power Converter : AC Drives

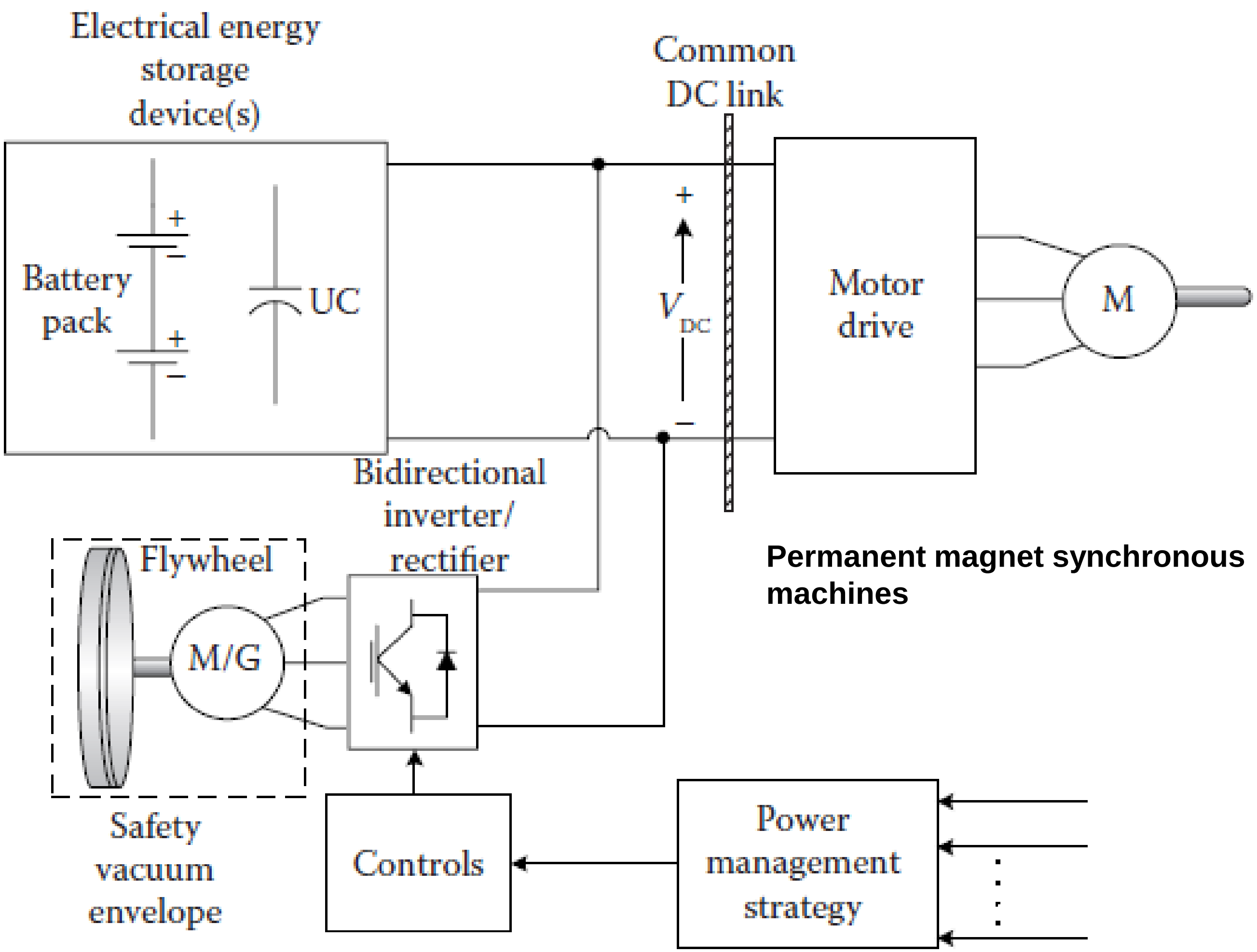
Cascaded converters configuration





Bidirectional DC/DC converter

Role of Power Converter : AC Drives



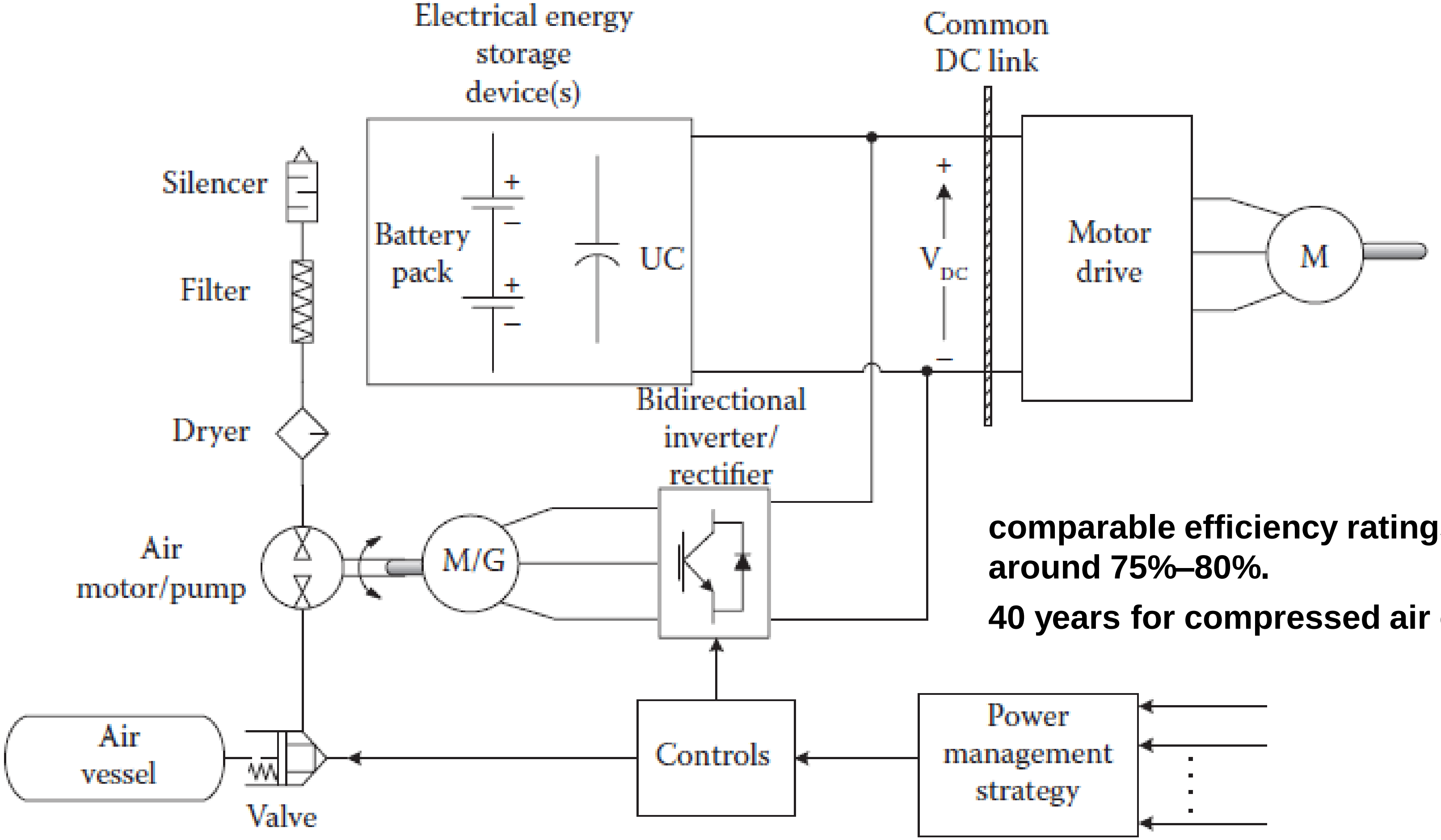
20,000 to 50,000 rpm

Typically 20 years

Permanent magnet synchronous machines

Whenever there is a surplus of braking or buffering energy, it can be delivered to the flywheel by operating the machine in motoring mode and the converter in inverter mode, and whenever the energy stored in the flywheel is needed for propulsion, the machine is operated in generator mode and the converter is operated in rectifier mode

Role of Power Converter : AC Drives

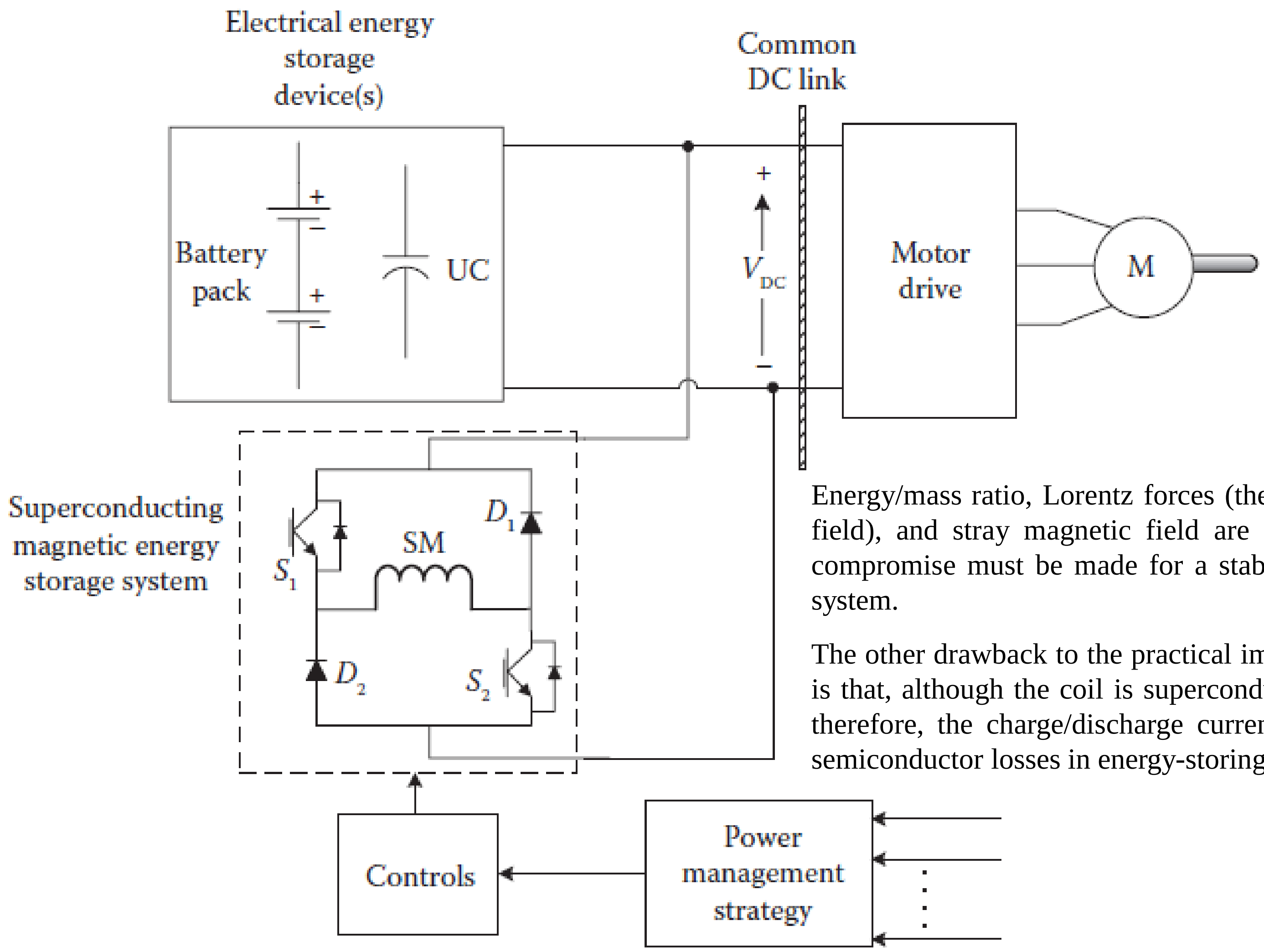


comparable efficiency ratings of around 75%–80%.

40 years for compressed air cases

- ✓ Whenever power is needed from the compressed air storage system, the converter is operated in rectifier mode and the electric machine is operated as a generator. In this mode, the pneumatic machine is driven directly by the compressed air that expands and is released from the air vessel.
- ✓ The pneumatic machine then drives a generator and power is supplied to the DC link via the power electronic converter. The power electronic converter and the valve of the air vessel are controlled based on the mode of operation and the amount of power that is to be delivered to/from compressed air storage system.

Role of Power Converter : AC Drives



Energy/mass ratio, Lorentz forces (the force due to the electromagnetic field), and stray magnetic field are the parameters between which a compromise must be made for a stable, reliable, and economic SMES system.

The other drawback to the practical implementation of an SMES system is that, although the coil is superconducting, the switches are not ideal; therefore, the charge/discharge current will gradually decrease due to semiconductor losses in energy-storing mode.