Hybrid Electric Vehicles**: EE 6435 D**

Module 2

Presented by

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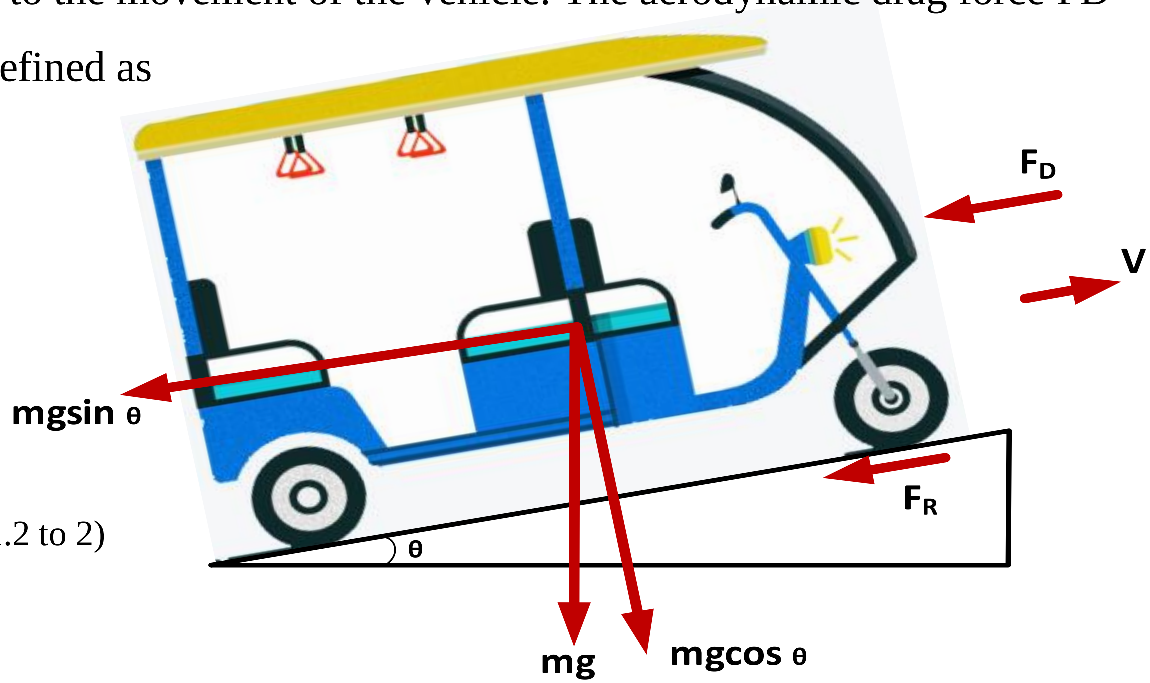
Design of Electric Vehicle

1. Aerodynamic Drag

Aerodynamic drag is the resistance of air to the movement of the vehicle. The aerodynamic drag force FD and power PD acting on the vehicle are defined as



$$F_D = 0.5*\rho*C_D*A*(V+V_{air})^2$$

ρ = Air density @ 27˚C = 1.2 kg/m3

CD = Drag coefficient (Standard value: 0.44)

V = Vehicle speed (m/s)

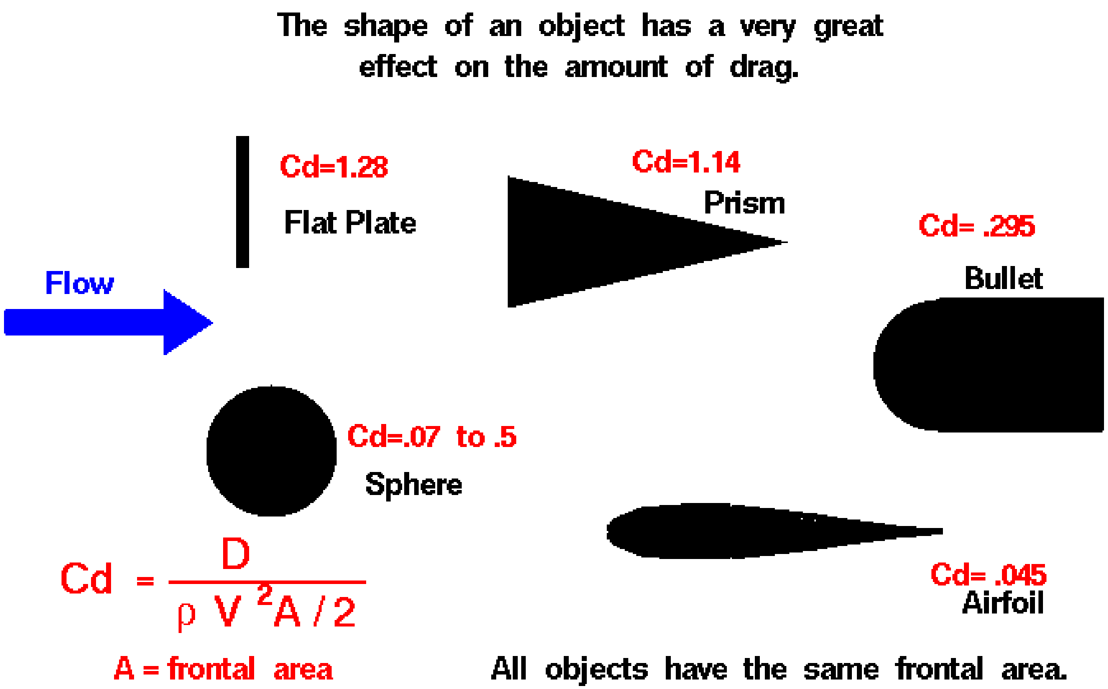
V_{air} = Wind Velocity (m/s)

A = Vehicle frontal area (sq. m) (Standard value:1.2 to 2)

- ✓ The drag force increases with the cross-sectional area of the vehicle and also increases or decreases depending on whether the vehicle is experiencing a headwind or a tailwind.

- ✓ A tailwind results in a negative speed and reduced drag, and the net air velocity relative to the vehicle (v − vair) is reduced, whereas a headwind results in a positive speed and increases the drag, as air has a velocity of (v + vair) relative to the car.

Design of Electric Vehicle



Distance $s = E_b v / P_D$

An electric vehicle has the following attributes: drag coefficient C_d = 0.25, vehicle cross section A = 2 m^2, and available propulsion energy of E_b = 20 kWh (1kWh = 3 6 × 10^6 J).
Let the density of air ρair = 1.2 kg m−3.
Instantaneously at a vehicle speed of 50 km/h, calculate the aerodynamic drag force, power, and range, while driving in (a) calm conditions with no wind and (b) windy conditions with a 12 km/h headwind and (c) windy conditions with a 12 km/h tailwind.

Design of Electric Vehicle

2. Rolling Resistance

The rolling resistance is the combination of all frictional load forces due to the deformation of the tire on the road surface and the friction within the drivetrain. The rolling resistance FR is described by the equation

$$F_R = m*g*\mu$$

m = Mass of the vehicle in kg including Payload (Typical values: Vehicle weight = 150 kg ; Payload = 218 kg including 1 driver (75 kg), 2 passengers (68 kg) and luggage (7 kg))

g = Acceleration due to gravity = 9.81 m/s^2

μ = Rolling resistance coefficient (Typical value: 0.013)

Note that the energy dissipated by the rolling resistance increases the tire temperature and pressure

Problem:

An electric vehicle has the following attributes: coefficient of rolling resistance μ = 0.0085 and vehicle mass of 2000 kg. Instantaneously at a vehicle speed of 10 km/h, calculate the rolling resistance and power. Let g = 9.81 m/s^2.

Design of Electric Vehicle

3. Gradient Resistance

The vehicle load power can increase or decrease depending on whether the car is ascending or descending an incline. The climbing resistance or downgrade force is given by

$$F_G = m*g*\sin\theta$$

θ = Angle of inclination

g = Acceleration due to gravity = 9.81 m/s^2

The climbing force is positive, resulting in motoring operation. The downgrade force is negative and can result in energy regeneration to the battery, a mode commonly used in electrically propelled vehicles rather than friction braking to slow the vehicle.

Problem:

A 20 kW rated Vehicle is traveling down a 6 in both positive and negative slope at 60 km/h and 30 km/h respectively. Assuming calm conditions, how much regenerative power is available to brake the vehicle while maintaining a constant speed? And also, calculate the power required to drive in positive slope.

Design of Electric Vehicle

4. Acceleration

Nominal vehicle power requirements are typically based on vehicle acceleration requirements, usually specified as the time to accelerate from 0 to 100 km/h (62 mph) or from 0 to 60 mph. Under these conditions, the maximum available torque and power of the propulsion system are likely to be required.

As per Newton's second law of motion for a linear system, the force required to accelerate or brake a vehicle Fa is given by

$$F_A = m*a = m\, dv/dt$$

s = Acceleration distance

a = Acceleration = Distance travelled / time

m = Mass of the vehicle in kg including Payload (Typical values: Vehicle weight = 150 kg ; Payload = 218 kg including 1 driver (75 kg), 2 passengers (68 kg) and luggage (7 kg))

Problem:

A Vehicle is having a weight of 1200 kg and the vehicle reaches to 0.1 km with in 5 seconds. Assuming calm conditions, how much the acceleration force is required and power consumption from the source during acceleration.

Design of Electric Vehicle

Summary of EV Design:

The force propelling the vehicle forward, the tractive effort, has to accomplish the following:

- ✓ overcome the rolling resistance;
- ✓ overcome the aerodynamic drag;
- ✓ provide the force needed to overcome the component of the vehicle's weight acting
- ✓ down the slope;
- ✓ accelerate the vehicle, if the velocity is not constant.

Total tractive effort

The total tractive effort is the sum of all these forces:

$$F_{tr} = F_D + F_R + F_G + F_A$$

where:

- F_R is the rolling resistance force;
- F_D is the aerodynamic drag;
- F_G is the hill climbing force;
- F_A is the force required to give acceleration.

We should note that F_A will be negative if the vehicle is slowing down, and that F_G will be negative if it is going downhill.

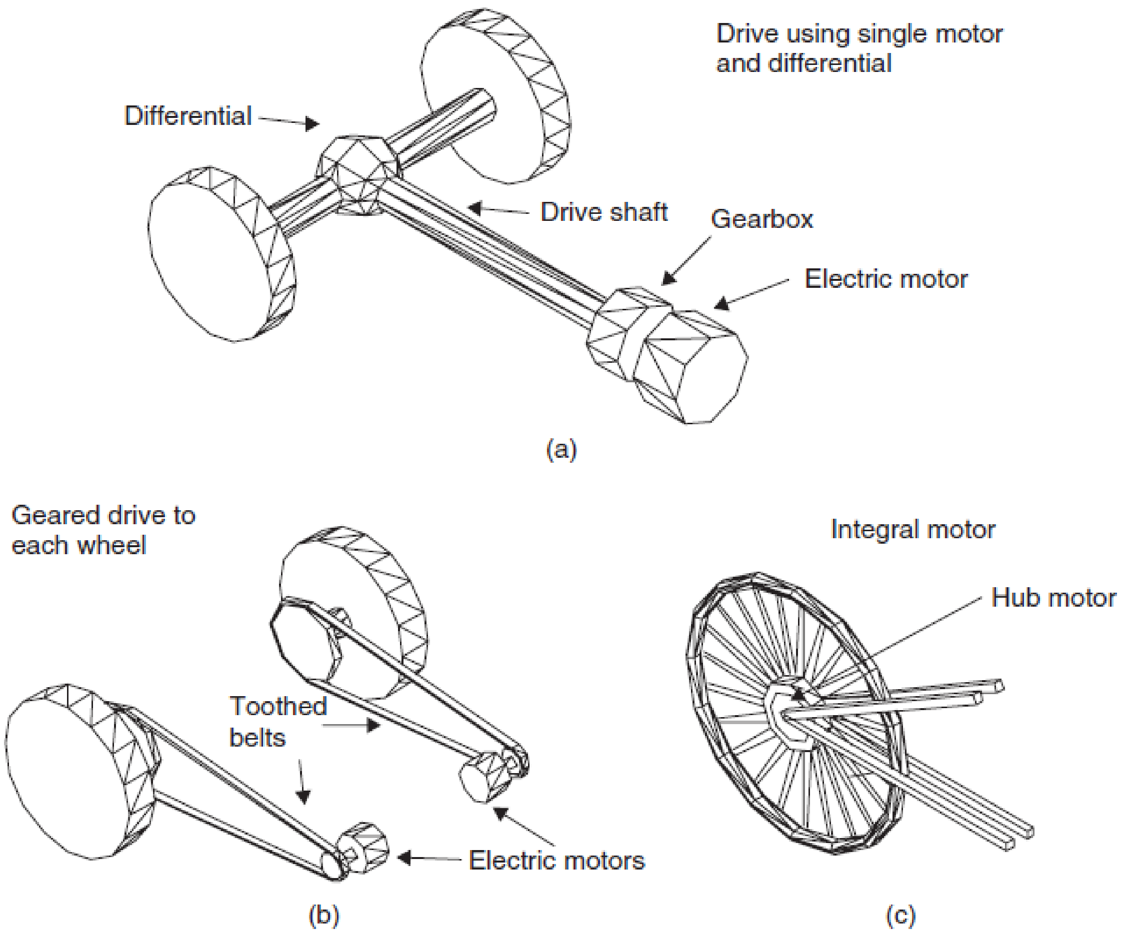
Design of Electric Vehicle

Transmission Efficiency

The transmission of electric vehicles is inherently simpler than that of IC engine vehicles.

To start with, no clutch is needed as the motor can provide torque from zero speed upwards.

Similarly, a conventional gearbox is not needed, as a single-ratio gear is normally all that is needed.



Three different arrangements for electric vehicle transmission: (a) drive using single motor and differential; (b) geared drive to each wheel; and (c) integral motor

Design of Electric Vehicle

Differential Drive:

The most conventional arrangement is to drive a pair of wheels through a differential. This has many advantages, Reliable, quantity-produced piece of engineering. The disadvantage is that some power is lost through the differential, and differentials are relatively heavy. It can also take up space in areas where the space can be usefully utilized.

Geared drive with toothed belt:

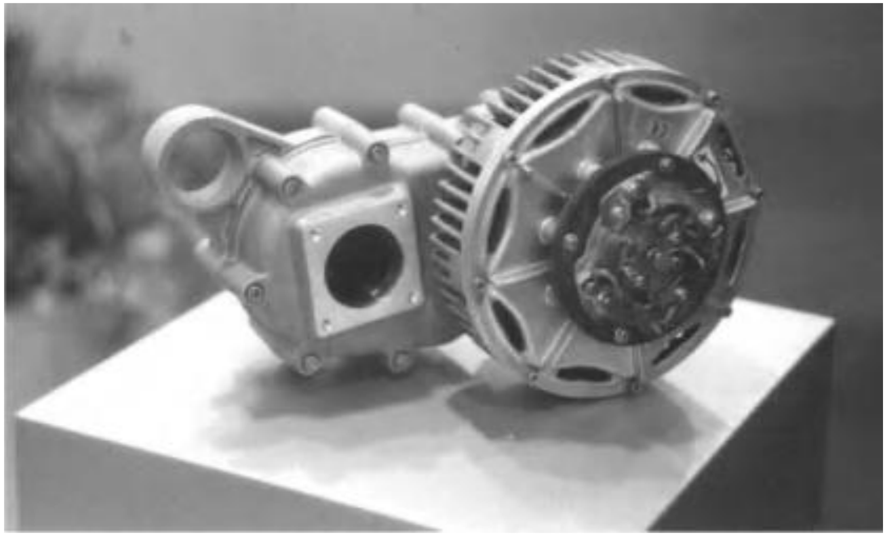
The differential can be eliminated by connecting a motor to each wheel via a single ratio gearbox or even a toothed belt drive. The torque from each wheel can be set by the electronic controller. This system has the advantage of clearing space within the vehicle, and the disadvantage of needing a more complicated electronic controller. Also, in terms of cost per kilowatt, two small motors are considerably more expensive than one larger one.

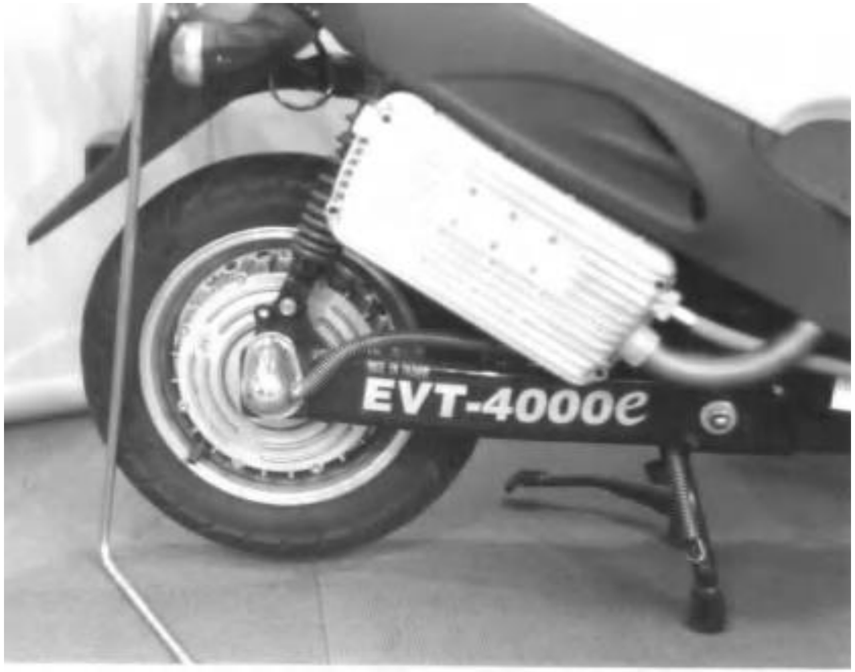
Integral Motor Drive:

The third method is to connect the motor directly to the wheels via a shaft, or actually to design the motor as part of the hub assembly.

This system has huge potential advantages, including a 100% transmission efficiency. The trouble with this system is that most electric motors typically run at two to four times faster than the vehicle's wheels, and designing a motor to work slowly results in a large heavy motor. However, this arrangement has and can be used. It is particularly popular in electric motors scooters and bicycles.

Design of Electric Vehicle





Integral Motor Drive:

Design of Electric Vehicle

Exercise Problems:

1. An Electric vehicle has to be designed with 1200 kg of net weight for the following assumptions, Drag coefficient C_d = 0.44, rolling resistance is 1.3 % of frictional load force, Frontier area = 2 m^2, battery is rated with 50 units of energy, Density of air ρ = 1.2 kg m^{-3}. The average speed is 50 km/h. Neglect the transient responses. Estimate the following,

1. The aerodynamic drag force, Rolling resistance force.
2. And also, calculate the maximum assured mileage of EV for 15 km/h head and tail wind velocity.
3. What is the H.P rating of the motor with power train efficiency of 88 %?
4. How much greater is the power requirement for climbing in 10 degree slope compared to a flat road?

2. An electric drive features a 24 kWh battery pack and has a range of 170 km at a constant speed of 88 km/h. What is the new range when traveling at 88 km/h if the heating, ventilation, and air conditioning draw a constant power of 6 kW?

3. On a 20° C sunny day with no wind speed, and an air density of 1.2 kg/m^3, a 1450 kg vehicle travels in roadway with a 6° grade at 100 km/h and a rolling resistance coefficient of 0.013. The vehicle has a frontal area of 2.05 m^2 and a drag coefficient of 0.32. Calculate the aerodynamic, grading, and rolling resistance forces.

Design of Electric Vehicle

4. An electric vehicle has the following attributes: mass m = 500 kg, wheel radius r = 0.3 m, gear ratio from rotor to drive axle n_g = 10, and a nominal gear efficiency ηg = 95%. The vehicle is required to accelerate linearly from 0 to 36 km/h in 5 s on a flat road surface under calm wind conditions. Neglecting load forces, calculate the electromagnetic torque from the electric motor to achieve this acceleration torque.

5. The vehicle of Problem 4 is required to decelerate linearly from 36 to 0 km/h in 5 s on a flat road surface under calm wind conditions. Neglecting load forces, instantaneously at 18 km/h calculate the regenerative torque to the electric motor to achieve this braking.

6. After some engine and transmission performance upgrades, the same vehicle is taken to a test track to find out the new vehicle top speed. The upgrades have increased engine torque to 450 Nm and engine horsepower to 300 kW and an overall powertrain efficiency of 88%. After the upgrades, the minimum gear ratio of the transmission is 0.9, and the differential gear ratio is 3.21. Calculate the maximum speed of the vehicle.

Design of Electric Vehicle

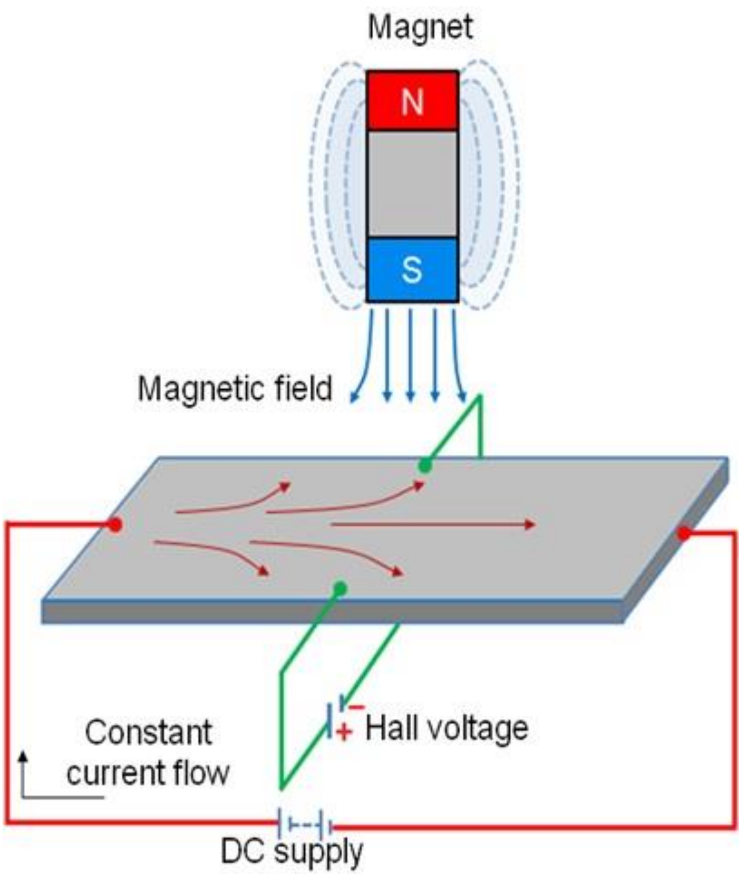
7. An electric car is climbing at 80 km/h up a 5° incline against a 10 km/h headwind. The vehicle has the following attributes: mass m = 1400 kg, drag coefficient C_d = 0.19, vehicle cross section A = 2.4 m^2, coefficient of rolling resistance C_R = 0.0044, wheel radius r = 0.3 m, gear ratio from rotor to drive axle n_g = 11, and a nominal gear efficiency ηg = 95%. Assume a density of air ρ_{air} = 1.2 kg m-3.

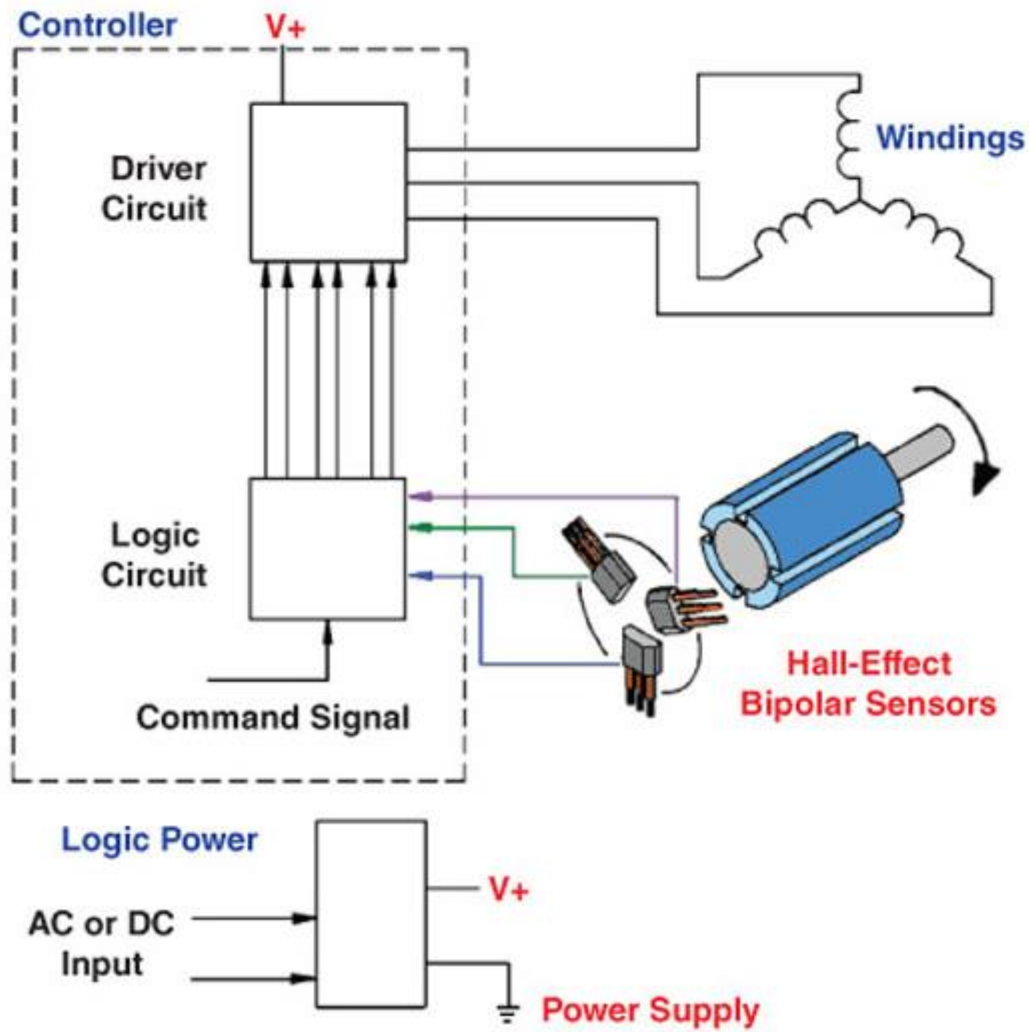
i) Calculate the rotor output torque and speed.

ii) How much greater is the power requirement for climbing the 5° slope compared to a flat road?

Brushless DC motor in EV Drives

Essential Elements:





Brushless DC motor in EV Drives

Mechanical Commutator Vs Electronic Commutator:

Mechanical Commutator	Electronic Commutator
It is made up of commutator segments and mica insulation. Brushes are made up of carbon or graphite.	Power Electronic switching devices are used in the commutator.
Commutator arrangement is located in the rotor.	Commutator arrangement is located in the stator.
Shaft position sensing is inherent in the arrangement.	It requires a separate rotor position sensor.
Number of commutator segments are very high.	Number of switching devices is limited to 6.
Sliding contact between commutator and brushes.	No sliding contacts.
Sparking takes place.	There is no sparking.
It requires a regular maintenance.	It requires less maintenance.
Difficult to control the voltage available across tapping's.	Voltage available across armature tappings can be controlled by PWM techniques.
Highly reliable.	Reliability can be improved by specially designed devices and protecting circuits.

Brushless DC motor in EV Drives

- ✓ BLDC Motor operation is based on the attraction or repulsion between magnetic poles.
- ✓ Using the three-phase motor as shown in figure below, the process starts when current flows through one of the three stator windings and generates a magnetic pole that attracts the closest permanent magnet of opposite pole.
- ✓ The rotor will move if the current shifts to an adjacent winding. Sequentially charging each winding will cause the rotor to follow in a rotating field.
- ✓ The torque in this example depends on the current amplitude and the number of turns on the stator windings, the strength and the size of the permanent magnets, the air gap between the rotor and the windings, and the length of the rotating arm.

Compared with a brushed DC motor or an induction motor, the BLDC motor has many advantages:

- ✓ Higher efficiency and reliability
- ✓ Lower acoustic noise
- ✓ Smaller and lighter
- ✓ Greater dynamic response
- ✓ Better speed versus torque characteristics
- ✓ Higher speed range
- ✓ Longer life

Brushless DC motor in EV Drives

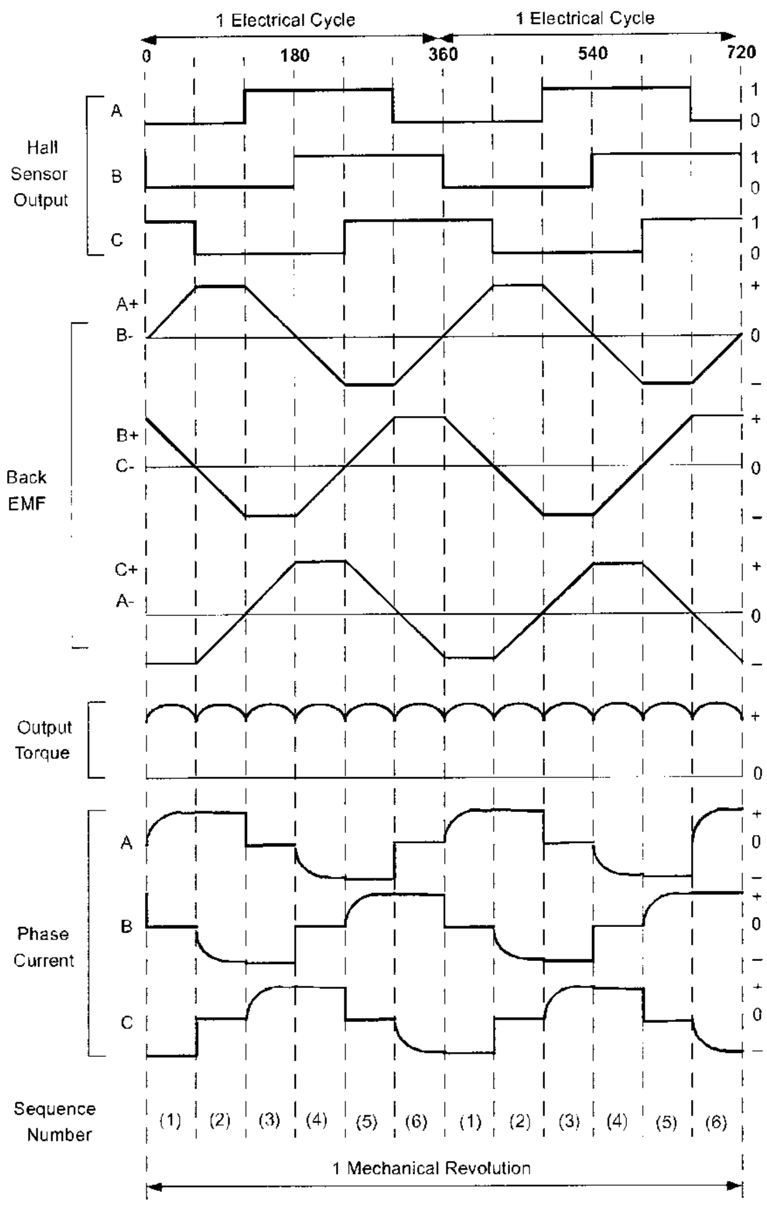
CW

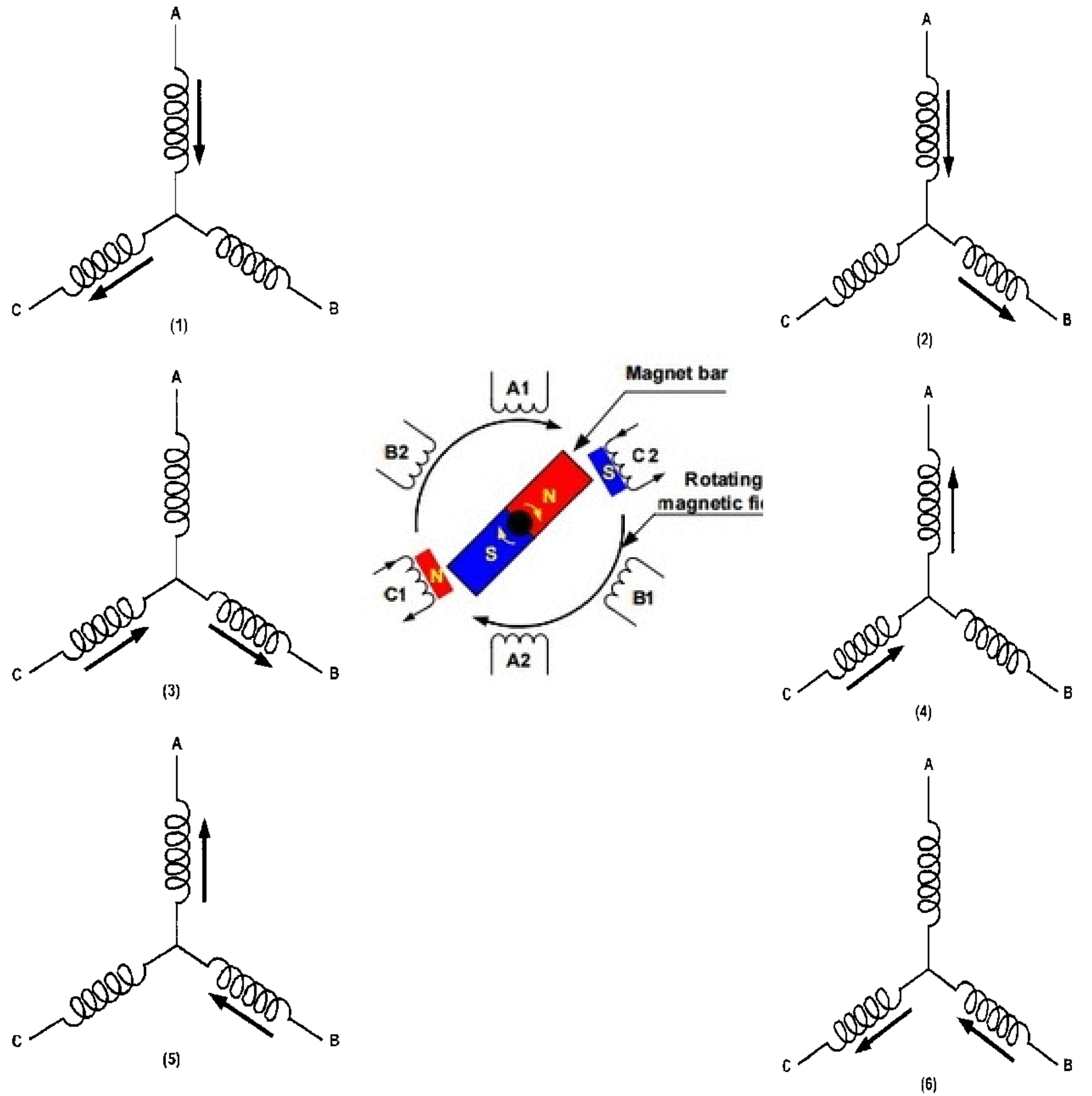
Sequence	Hall Sensor Input			Active PWM		Phase Current		
1								
2								
3								
4								
5								
6								

CCW

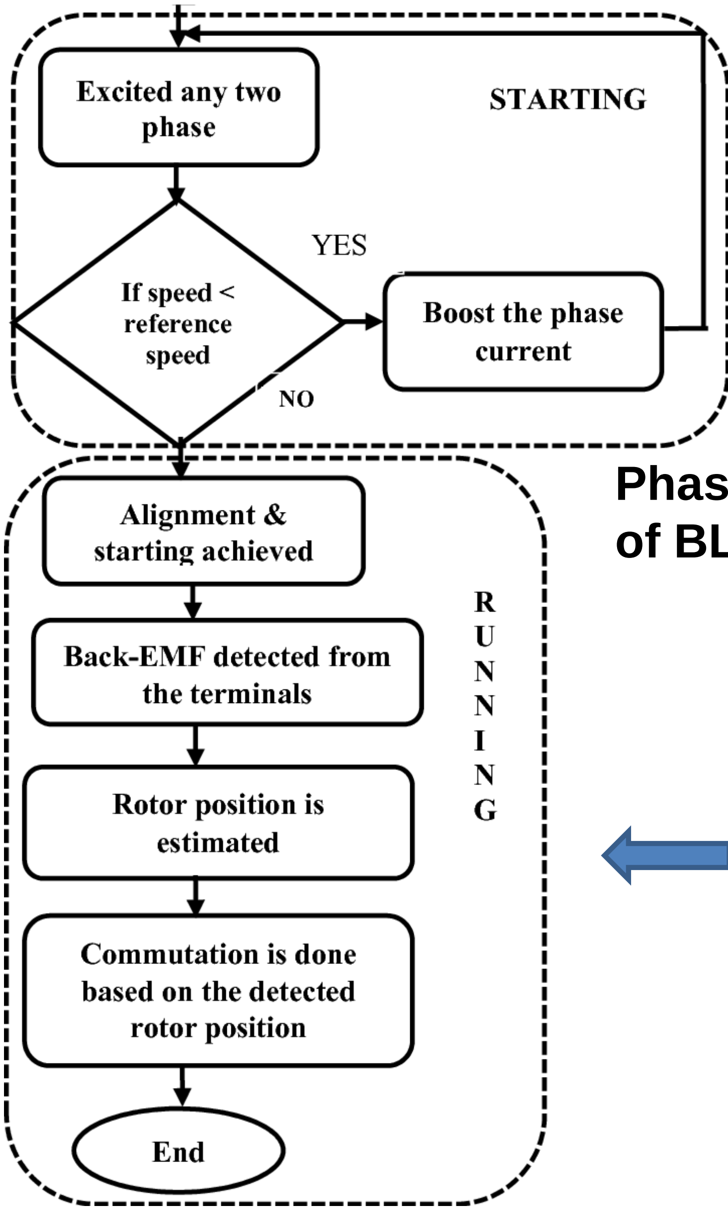
Sequence	Hall Sensor Input			Active PWM		Phase Current		
1								
2								
3								
4								
5								
6								

Brushless DC motor in EV Drives



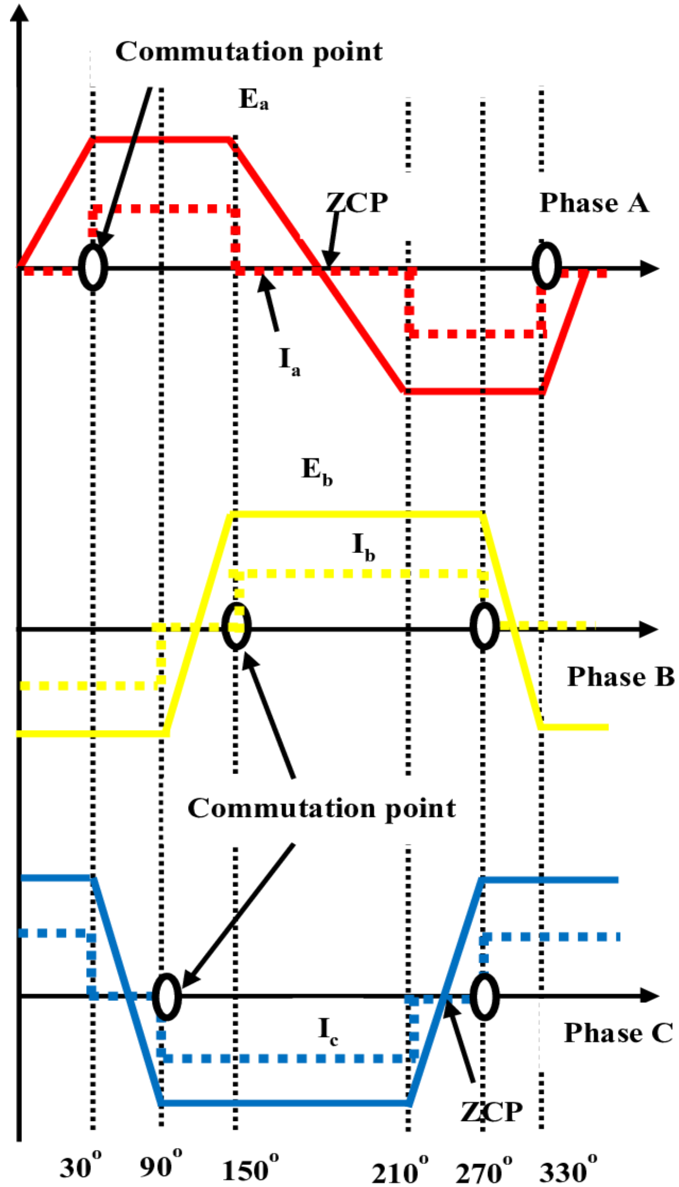


Brushless DC motor in EV Drives

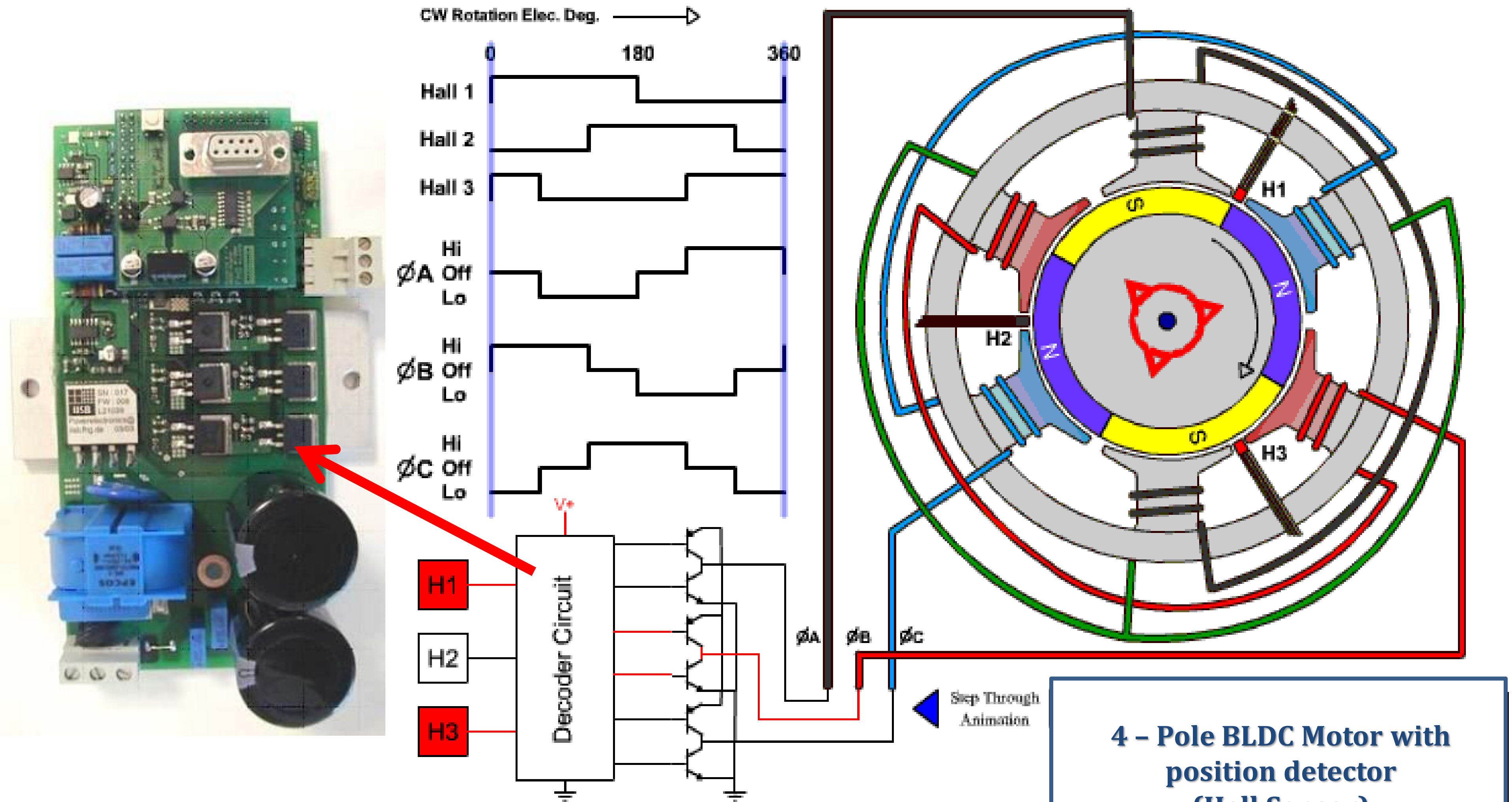


Phase Back EMF of BLDC Motor

Flowchart of the Back-EMF Zero Crossing Speed Sensing



Brushless DC motor in EV Drives



4 – Pole BLDC Motor with position detector (Hall Sensor)

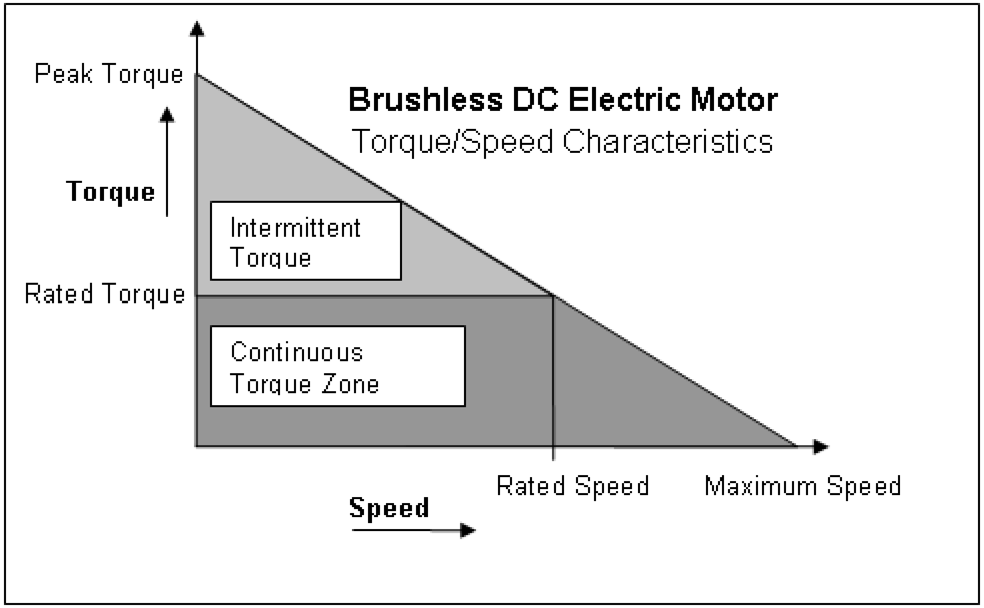
Brushless DC motor in EV Drives

Speed-torque Characteristics

The speed is essentially controlled by the voltage, and may be varied by varying the supply voltage. The motor then draws just enough current to drive the torque at this speed. As the load torque is increased, the speed drops, and the drop is directly proportional to the phase resistance and the torque. The voltage is usually controlled by chopping or PWM.

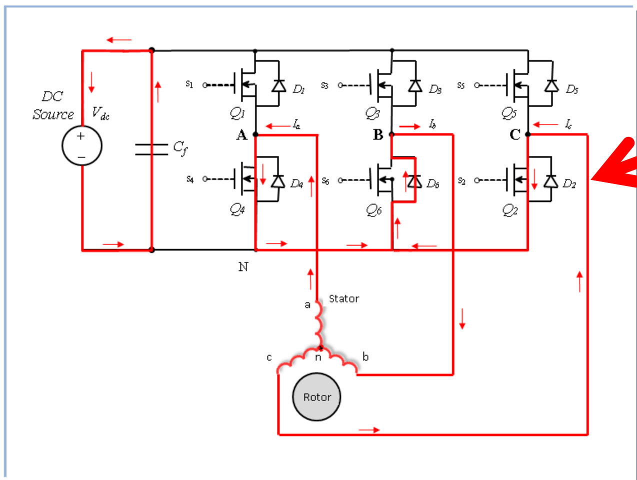
This gives rise to a family of torque/speed characteristics in the boundaries of continuous and intermittent operation. The continuous limit is usually determined by heat transfer and temperature rise.

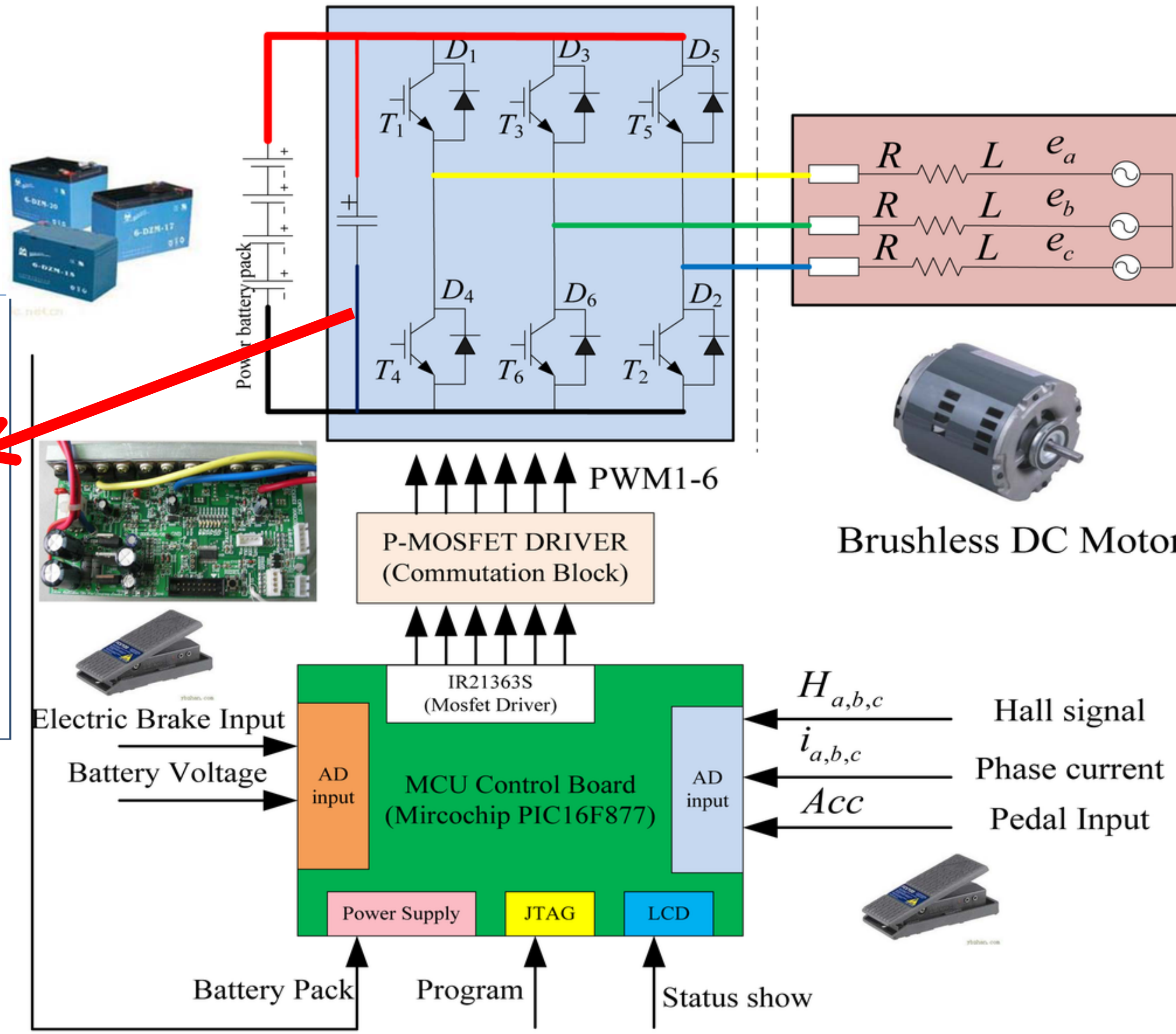
The intermittent limit may be determined by the maximum ratings of semiconductor devices in the controller, or by temperature rise. In practice the torque/speed characteristic deviates from the ideal form because of the effects of inductance and other parasitic influences.



Brushless DC motor in EV Drives

Regenerative braking

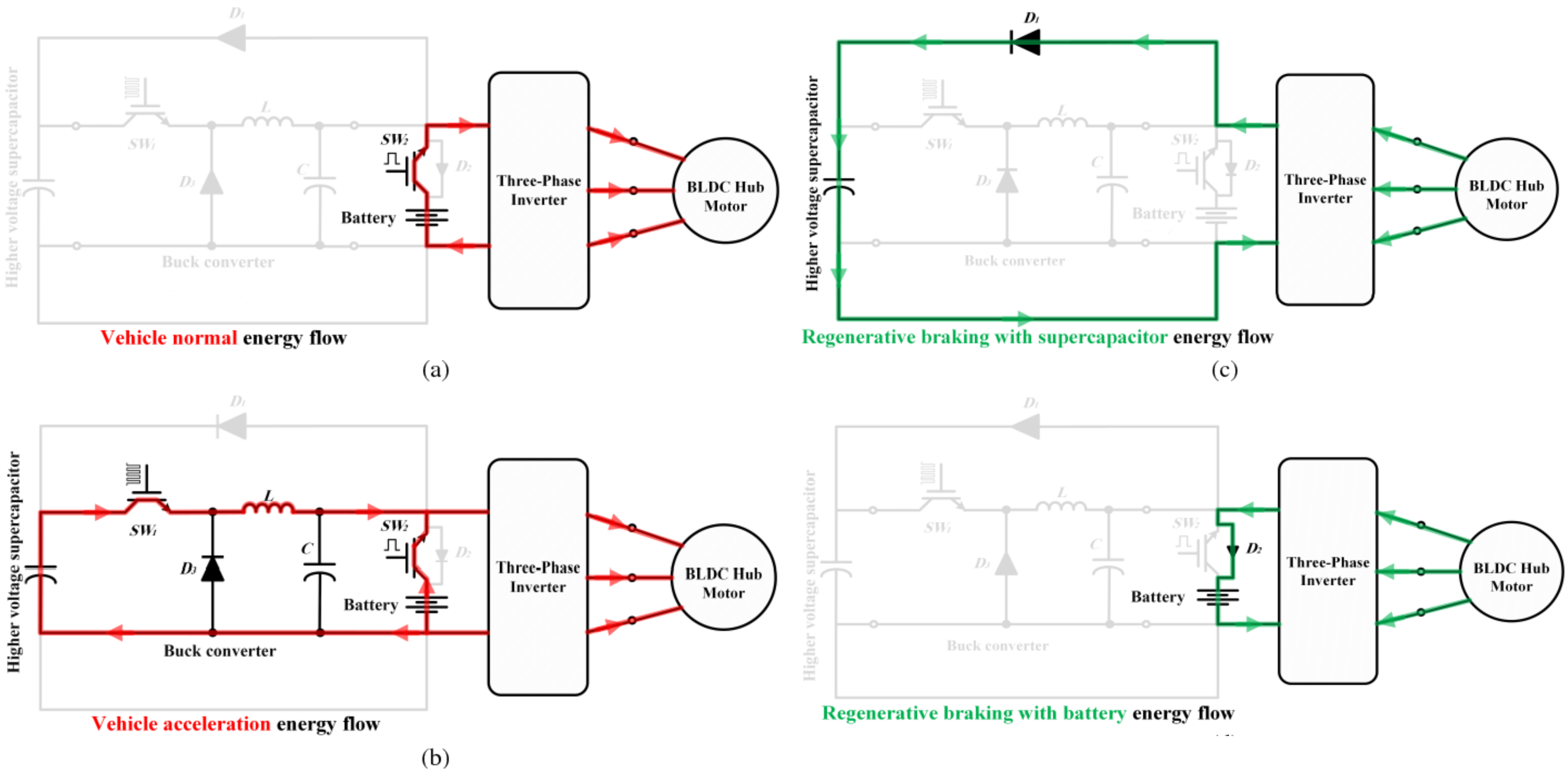




Regeneration Mode Table???

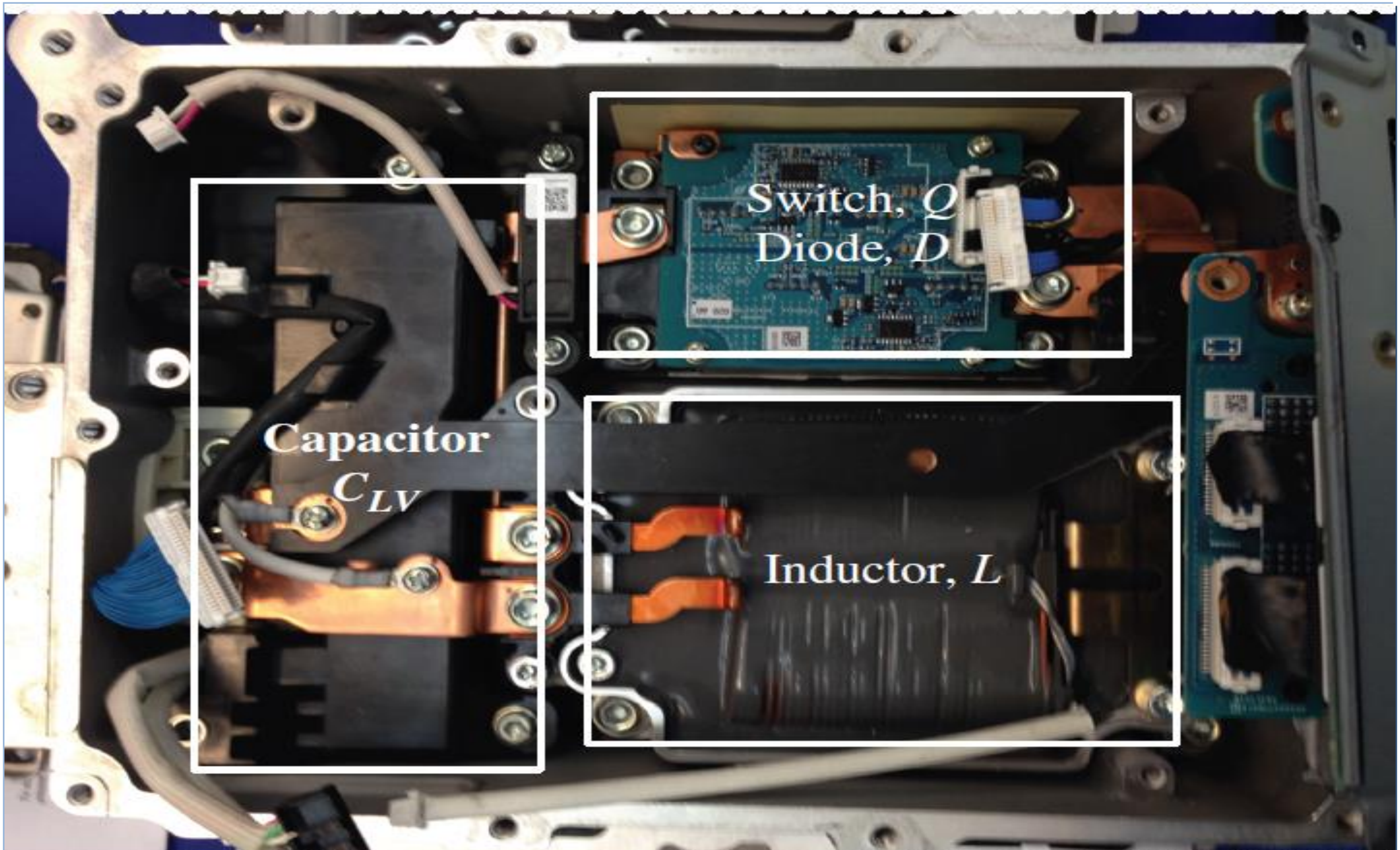
Brushless DC motor in EV Drives

Regenerative braking



Brushless DC motor in EV Drives

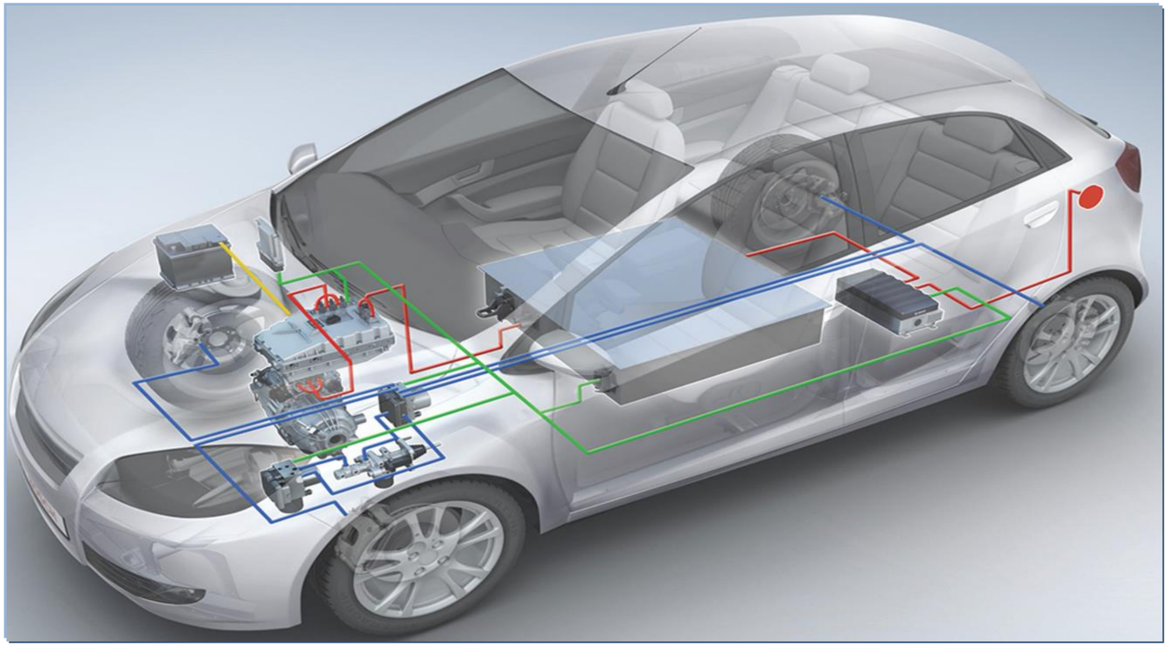
HEV bidirectional dc-dc converter



PM Synchronous Motors in EV Drives

- **Construction**
  - ✓ Stator identical to that of a three-phase induction motor – now called the “armature”
  - ✓ Energize from a three-phase supply and develop the rotating magnetic field
  - ✓ Rotor has a DC voltage applied (excitation)
  - ✓ Rotor could be a permanent-magnet type
- **Operation**

Magnetic field of the rotor “locks” with the rotating magnetic field – rotor turns at synchronous speed

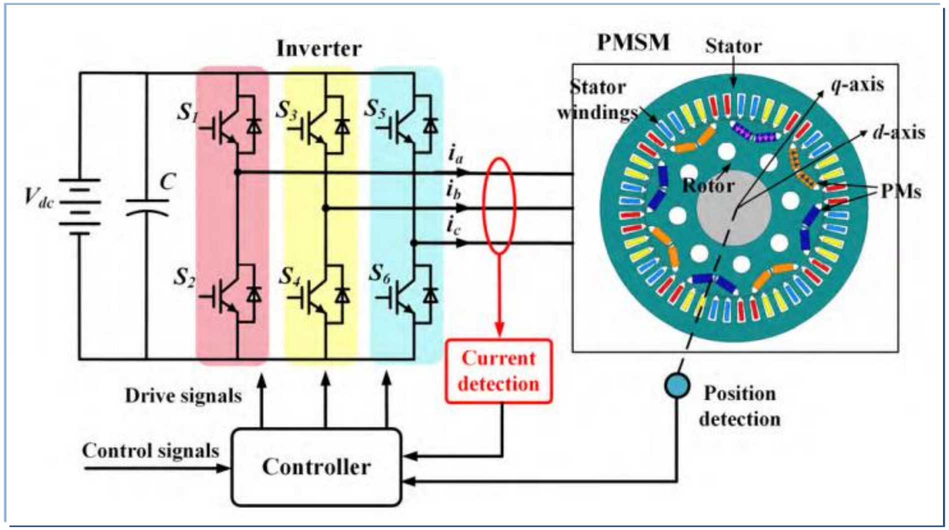


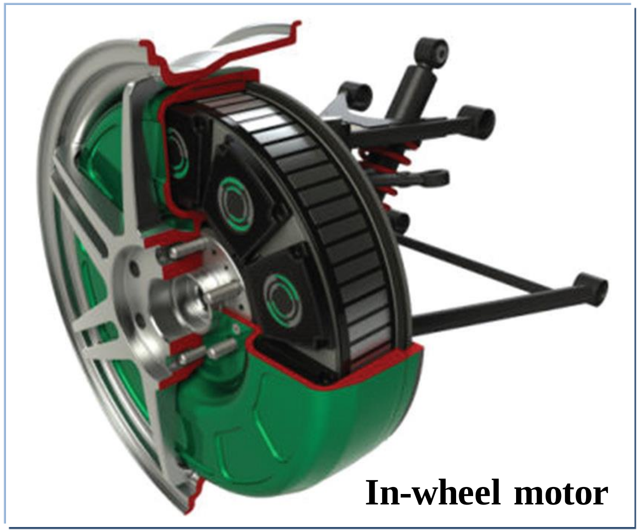
PM Synchronous Motors in EV Drives

Limitations in PMSM for EV Drives

- ✓ In PMSM Drives , the stator supply frequency is controlled from outside by using a separate oscillator.
- ✓ The frequency is changed from one value to the other gradually so that the difference between synchronous speed and rotor speed is small during any speed change.
- ✓ This gradual change in frequency helps the rotor to follow the stator speed properly at all operating points.
- ✓ When the desired speed is reached, the rotor gets locked with the stator flux speed (rotor pulls into step) after hunting oscillations.
- ✓ The frequency command f* is applied to the VSI through a delay circuit. This delay circuit ensures that the rotor follows the stator speed.

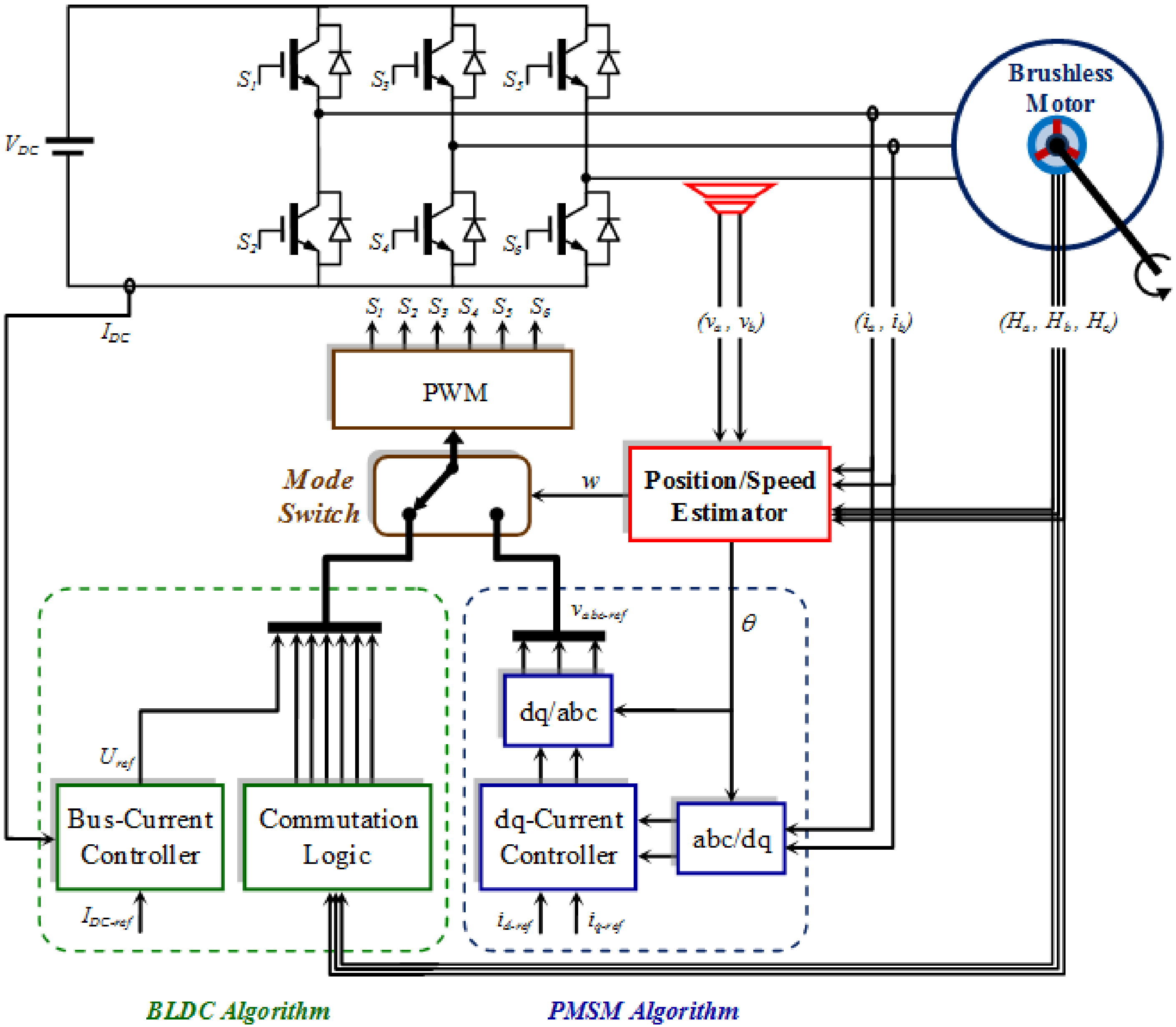
PM Synchronous Motors in EV Drives





- ✓ With position based control, the stator supply frequency is changed proportional to the rotor speed.
- ✓ Hence the stator rmf rotates at the same speed as the rotor speed.
- ✓ It means that the instants at which the switching devices operate to turn the stator windings ON and OFF is determined by the rotor position sensors.
- ✓ With the increase in the speed of EV, if the rotor slows down, then the stator supply frequency automatically changes so that the rotor remains synchronized with the rotating field.
- ✓ This ensures that the rotor moves in synchronism with stator at all operating points of EV.
- ✓ Consequently this controlled mechanism will never come out of synchronism or step.
- ✓ It does not suffer from hunting oscillations.

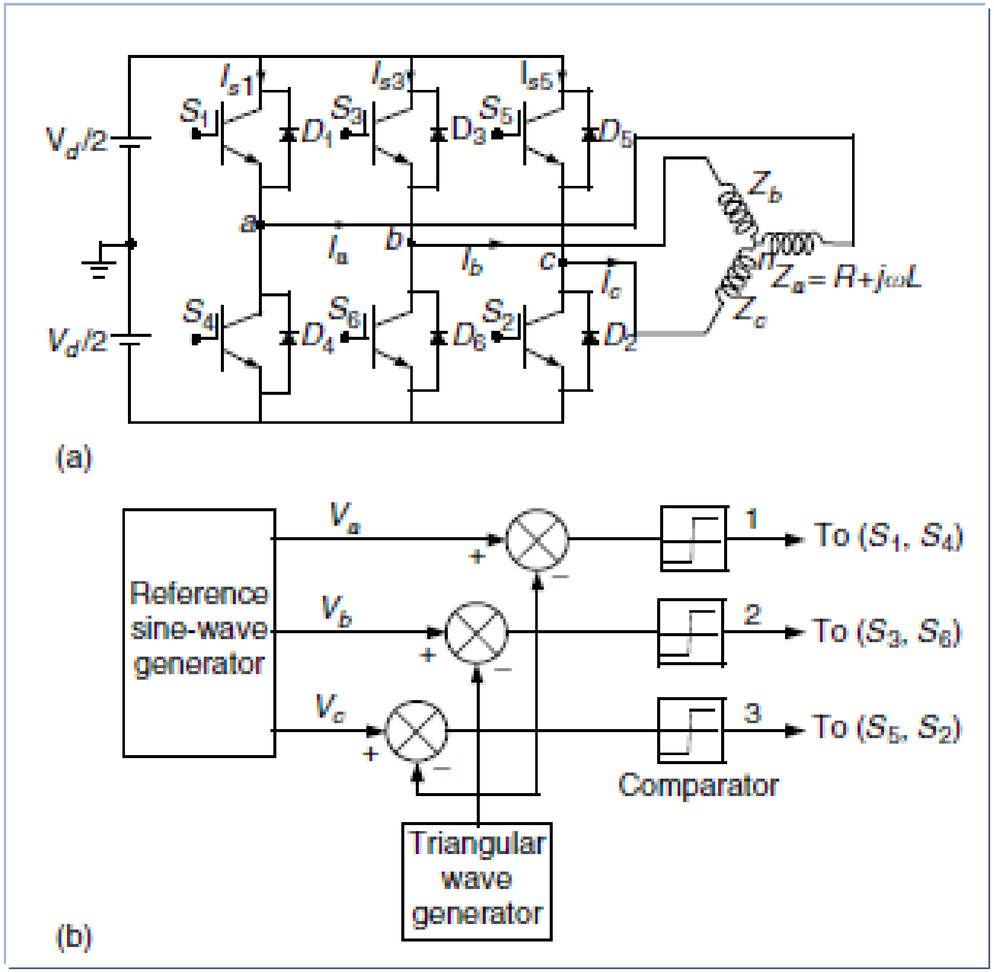
Hybrid Drives (PMSM and BLDC) for EV

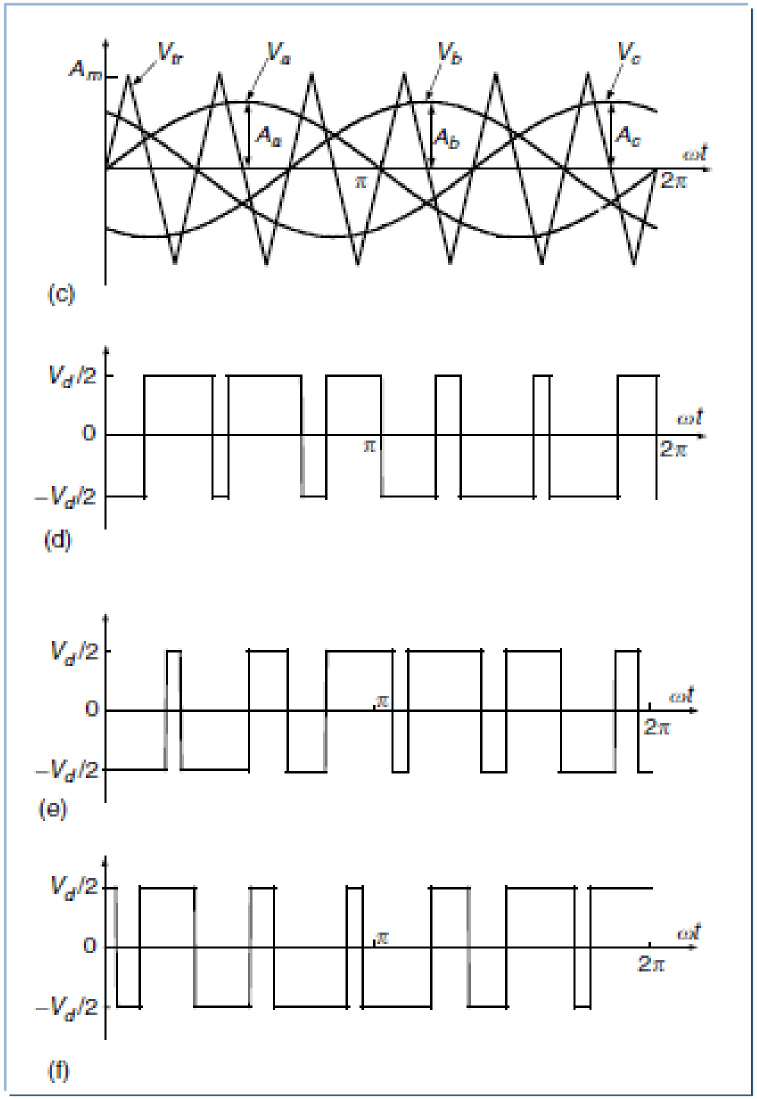


Comparison of BLDC Motor with DC Motor and IM

Futures	BLDC motor	DC motor	Induction motor (IM)
Speed-torque characteristics	Flat in nature as the result it can operate at all speeds with rated load	Moderately flat, at higher speed brush friction increases reduction of useful torque.	Non-linear, it enables lower torque at lower speeds
Efficiency	High	Moderate	Less
Rotor inertia	Lower and hence better dynamic characteristics	Higher and hence limited dynamic response time.	Higher and hence Poor dynamic characteristics
Electric noise	Less	High– because of brushes	Less
Speed range	Higher - no losses in brushes	Moderate – loses in brushes	Lower – determined by the Ac line frequency; increases in load further reduces speed
Control requirements	A controller is always required to control the commutation sequence	No controller is required for a fixed speed; controller required for variable speed	No controller is enquired for a fixed speed; controller required for variable speed
Commutation method	Using solid state switches	Mechanical contacts between brushes and commutator	The special starting circuit is required
Maintenance	Less maintenance	Periodic maintenance because of brushes	Less maintenance
Cost	Expensive	Cheaper	Cheaper

Induction Motor in EV Drives (VV-VF)

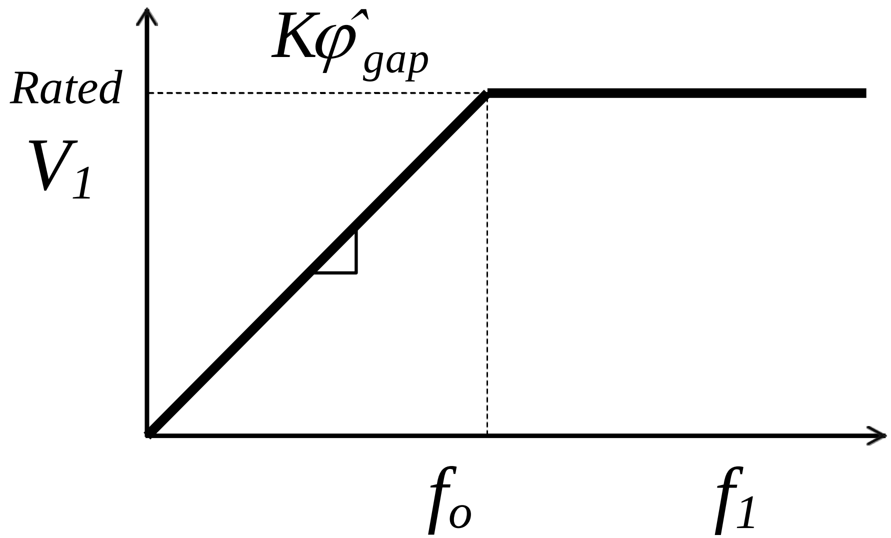




$$V_{An,1} = m \cdot \frac{V_d}{2\sqrt{2}} = 0.354 m V_d$$

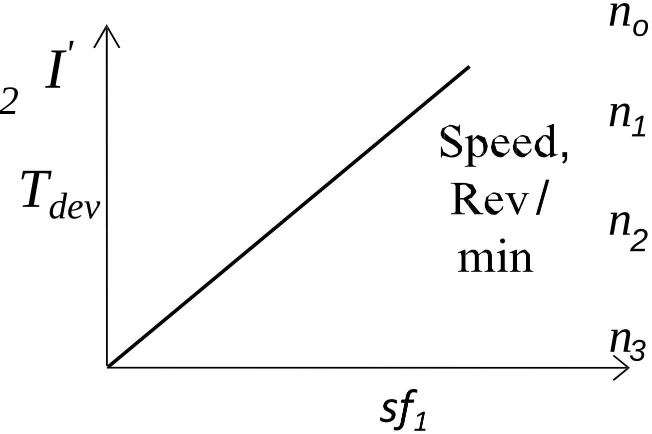
where m is the depth of modulation

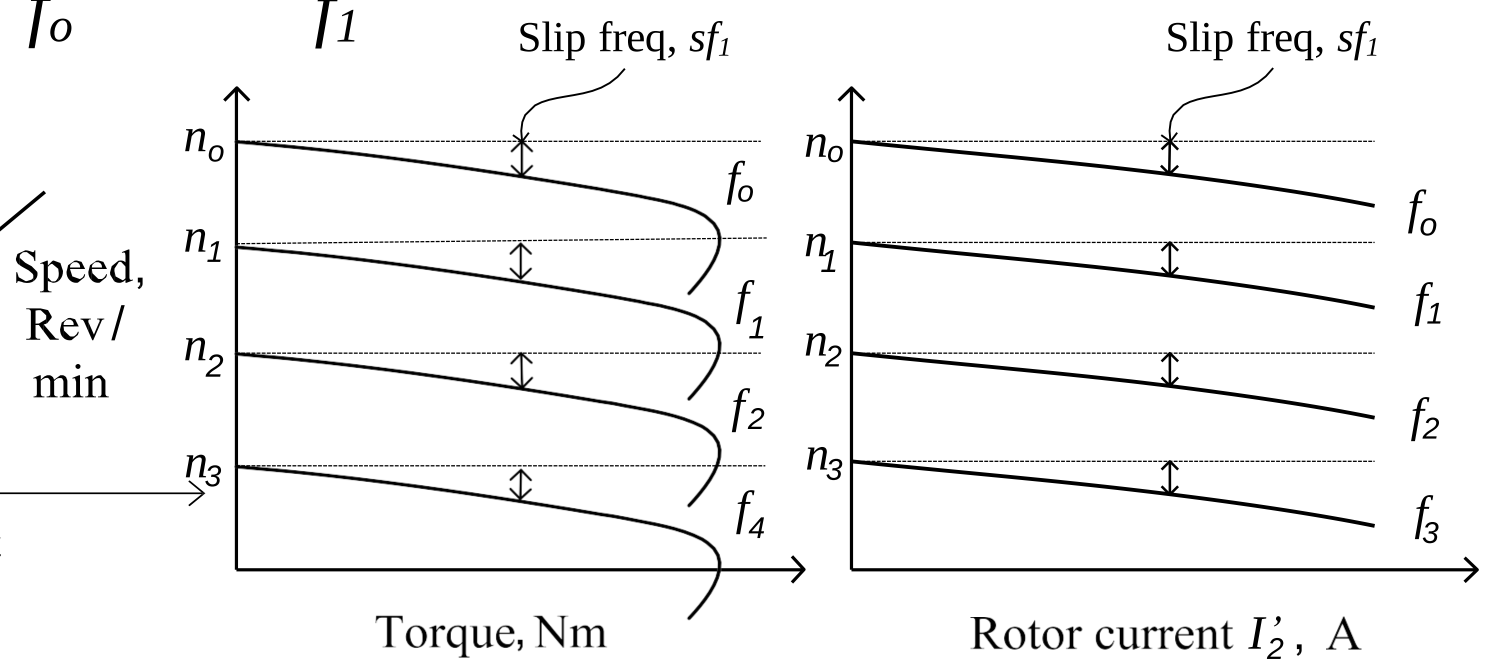
Induction Motor in EV Drives (VV-VF)



Benefits: .

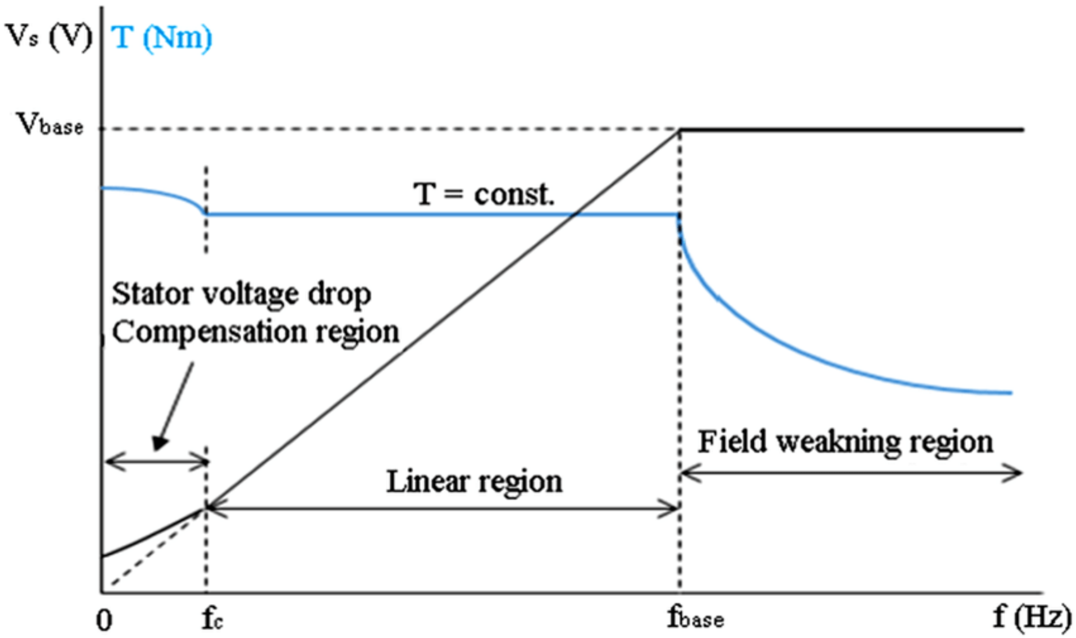
- ✓ Simple installation and maintenance.
- ✓ Low motor starting current.
- ✓ Energy savings.
- ✓ Reduced mechanical and thermal stress on motors and belts during start.
- ✓ High power factor

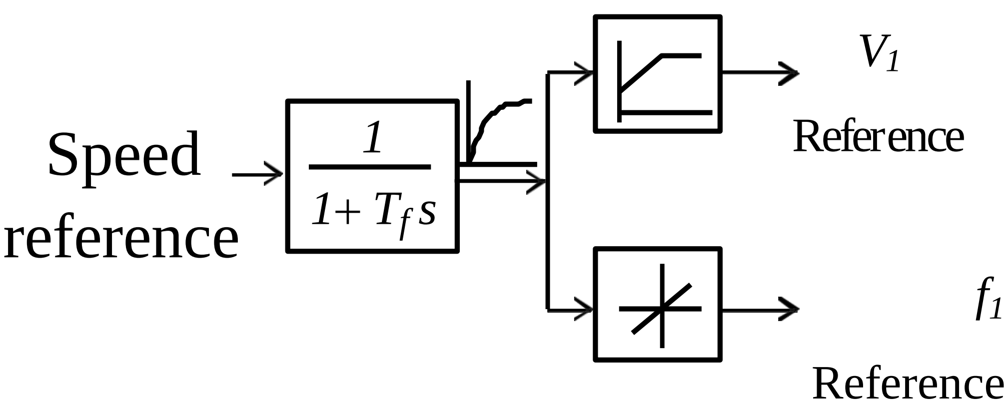




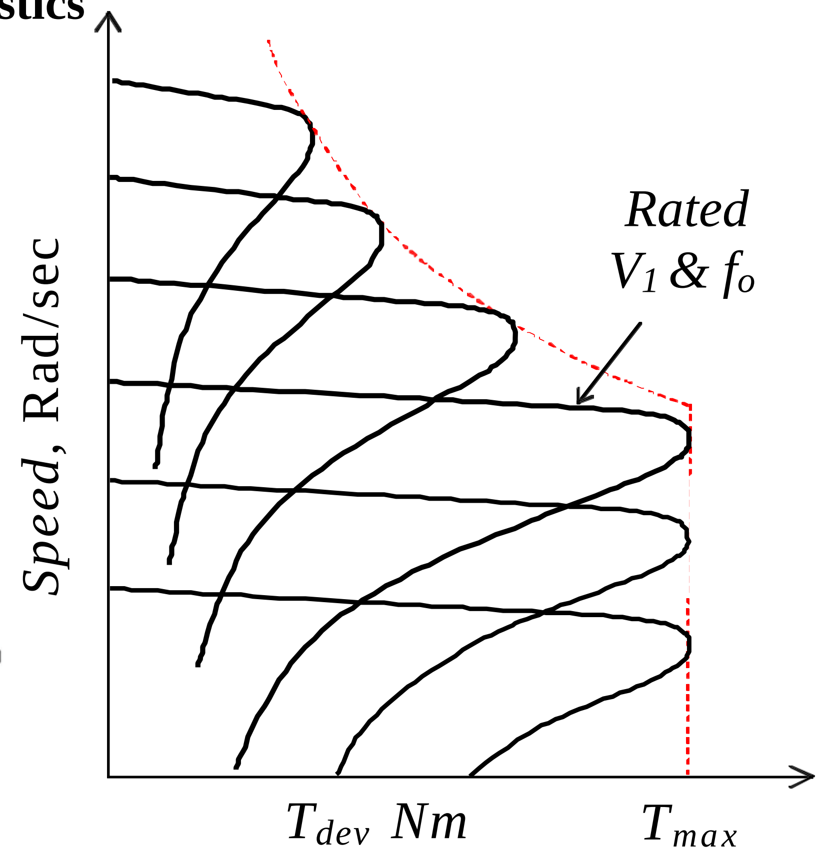
Induction Motor in EV Drives (VV-VF)

Constant max torque and power characteristics



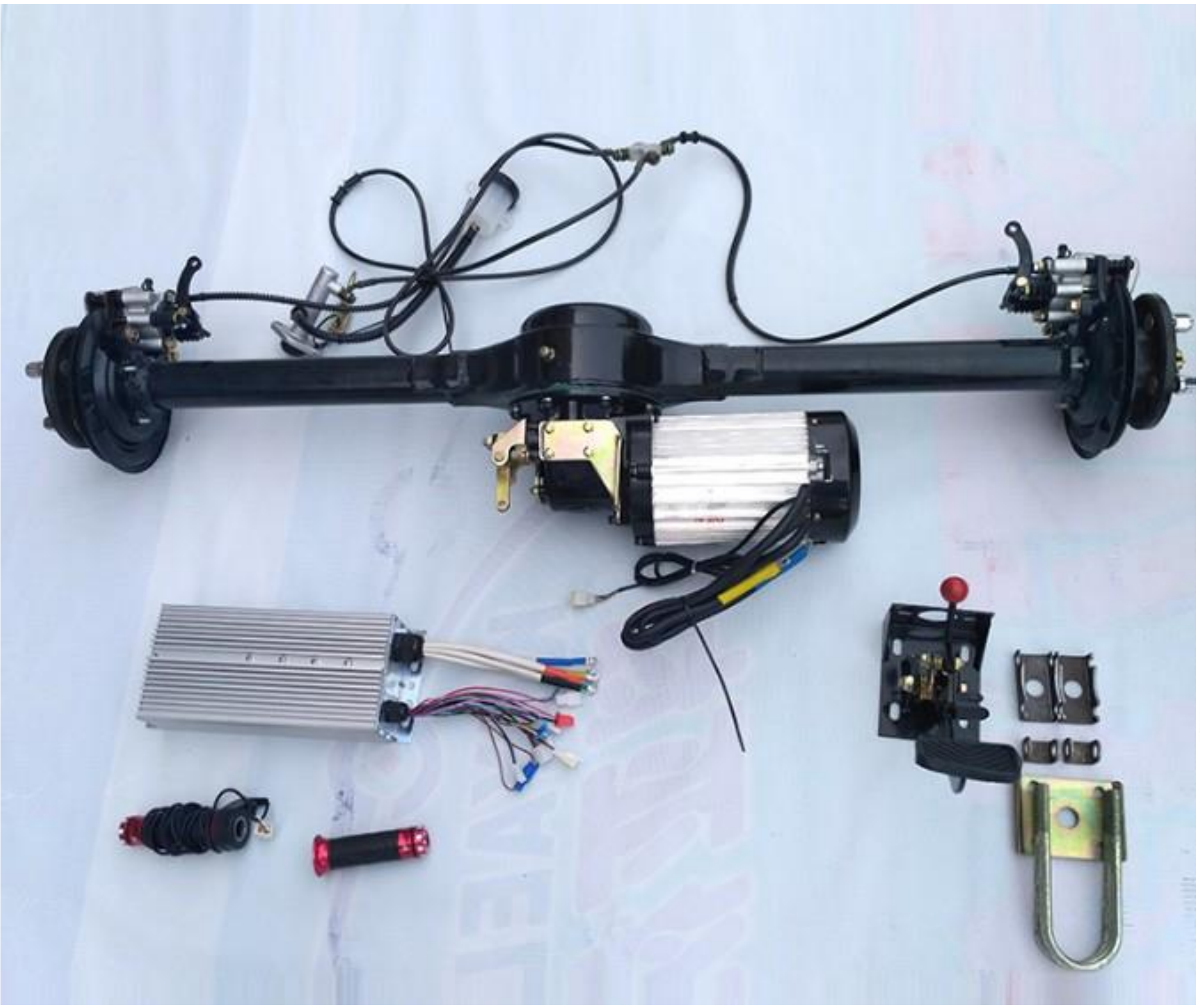


Simple *V/f* controller



T- ω characteristics under VVVF drive with f_1 below and above f_o

Induction Motor in EV Drives (VV-VF)

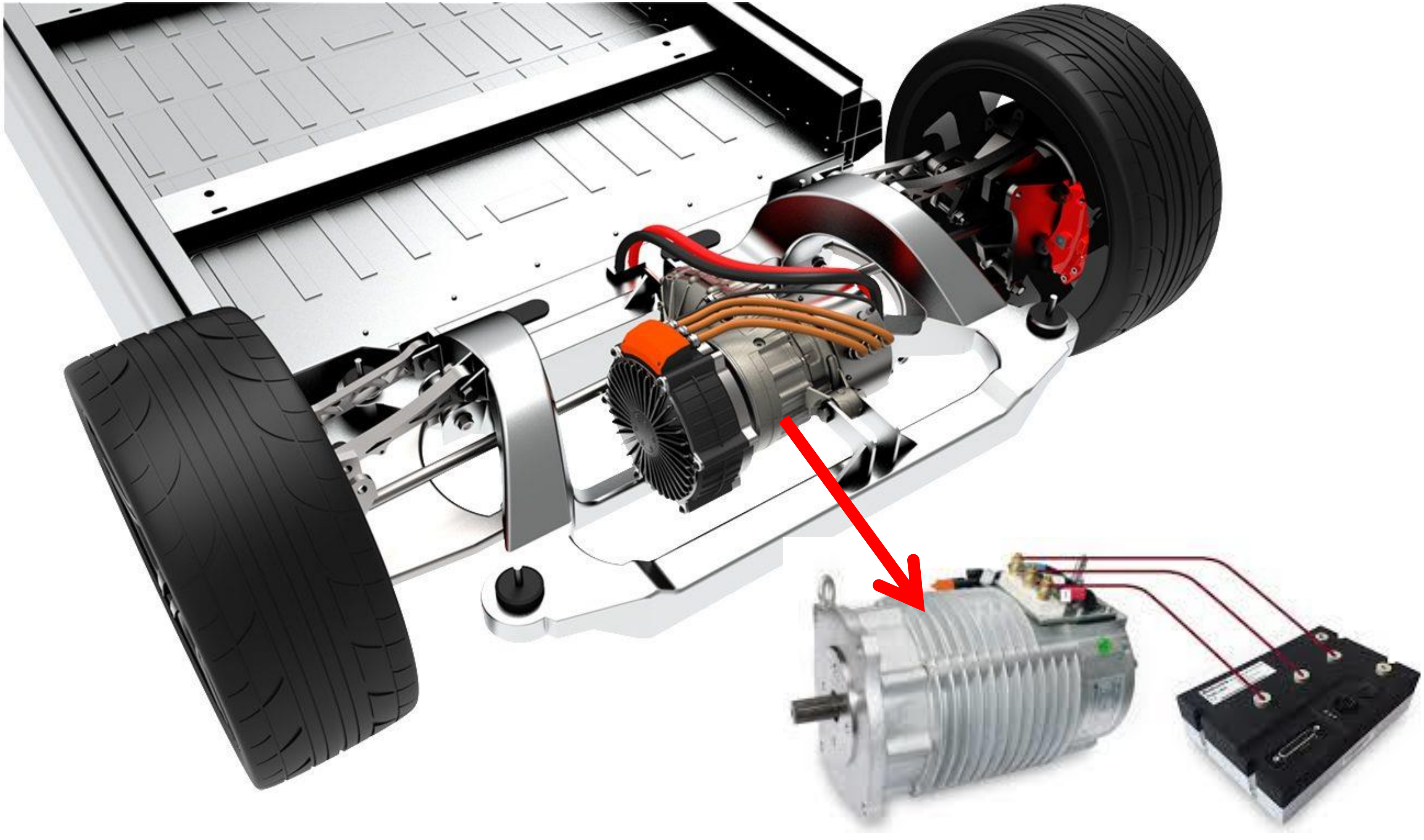


Rear Axle System

0-5k Ohm Hand throttle

0-5k Ohm
foot pedal throttle

Induction Motor in EV Drives (VV-VF)



Induction Motor in EV Drives (VV-VF)

Top Manufacturers List in EV

Top Manufacturers in EV field:

- ✓ Tesla Model 3
- ✓ BMW i3
- ✓ Chevy Bolt
- ✓ Chevy Spark
- ✓ Nissan LEAF
- ✓ Ford Focus Electric
- ✓ Hyundai Ioniq
- ✓ Karma Revera
- ✓ Kia Soul
- ✓ Mitsubishi i-MiEV
- ✓ Tesla Model S
- ✓ Tesla X
- ✓ Toyota Rav4
- ✓ Volkswagen e-Golf

Top Manufacturers in EV/PHEV field:

- ✓ Chevy Volt
- ✓ Chrysler Pacifica
- ✓ Ford C-Max Energi
- ✓ Ford Fusion Energi
- ✓ Mercedes C350e
- ✓ Mercedes S550e
- ✓ Mercedes GLE550e
- ✓ Mini Cooper SE Countryman
- ✓ Audi A3 E-Tron
- ✓ BMW 330e
- ✓ BMW i8
- ✓ BMW X5 xdrive40e
- ✓ Fiat 500e
- ✓ Hyundai Sonata
- ✓ Kia Optima
- ✓ Porsche Cayenne S E-Hybrid
- ✓ Porsche Panamera S E-hybrid
- ✓ Toyota Prius
- ✓ Volvo XC90 T8