ELECTRIC VEHICLE DESIGN USING MATLAB

Submitted in partial fulfilment of the requirements for the
Professional training – I of
Bachelor of Engineering Degree in
Electrical and Electronics Engineering

BY

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SCHOOL OF ELECTRICAL AND ELECTRONICS

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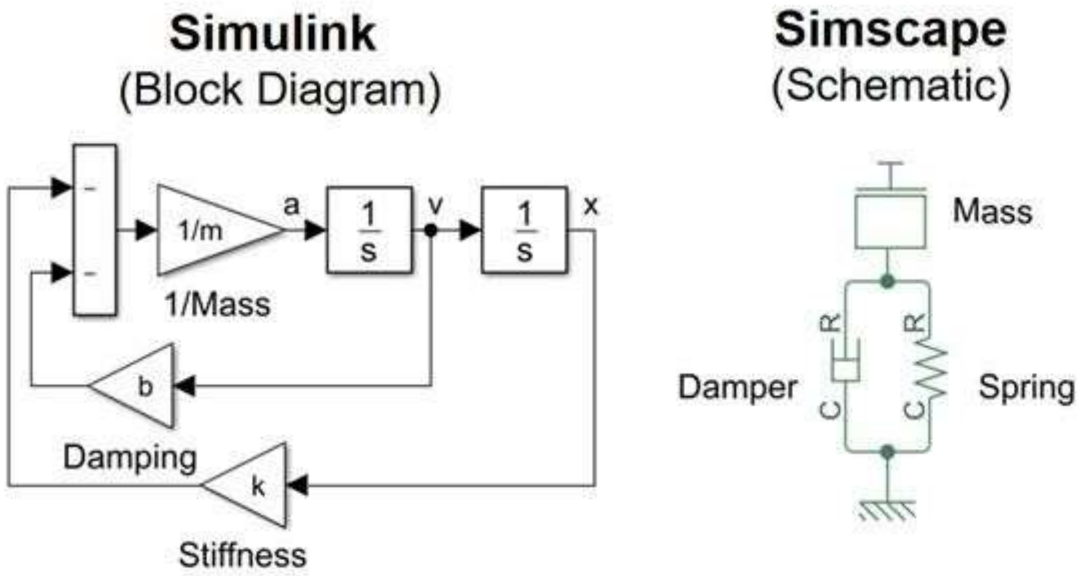
MATLAB- MATRIX Laboratory

MATLAB is a multi-paradigm programming language and numeric computing environment Tool
MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages
Simulink is a MATLAB-based graphical programming environment for modeling, simulating and analyzing multidomain dynamical systems.
Simscape enables you to create models of physical systems within the Simulink environment.

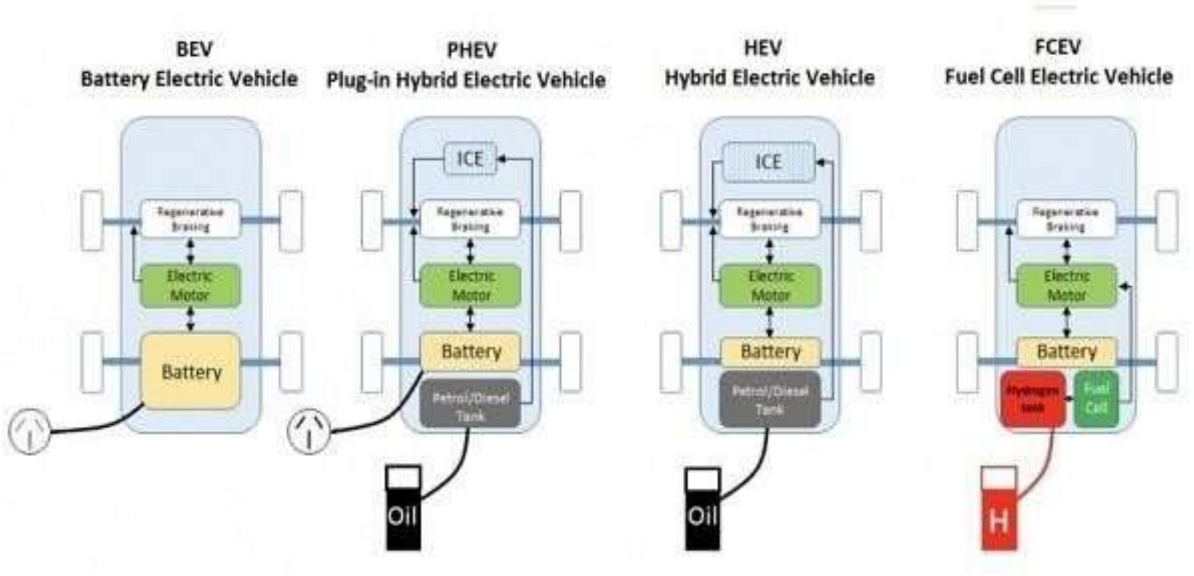


ELECTRIC VEHICLE (EV)

An EV is a shortened acronym for an electric vehicle. EVs are vehicles that **are either partially or fully powered on electric power**. Electric vehicles have low running costs as they have less moving parts for maintaining and also very environmentally friendly as they use little or no fossil fuels (petrol or diesel).

There are 4 (four) types of electric cars, with the following outline:

- Battery Electric Vehicle (BEV)
- Hybrid. Hybrid Electric Vehicle (HEV) Plug-in Hybrid Electric Vehicle (PHEV)
- Fuel Cell Electric Vehicle (FCEV)

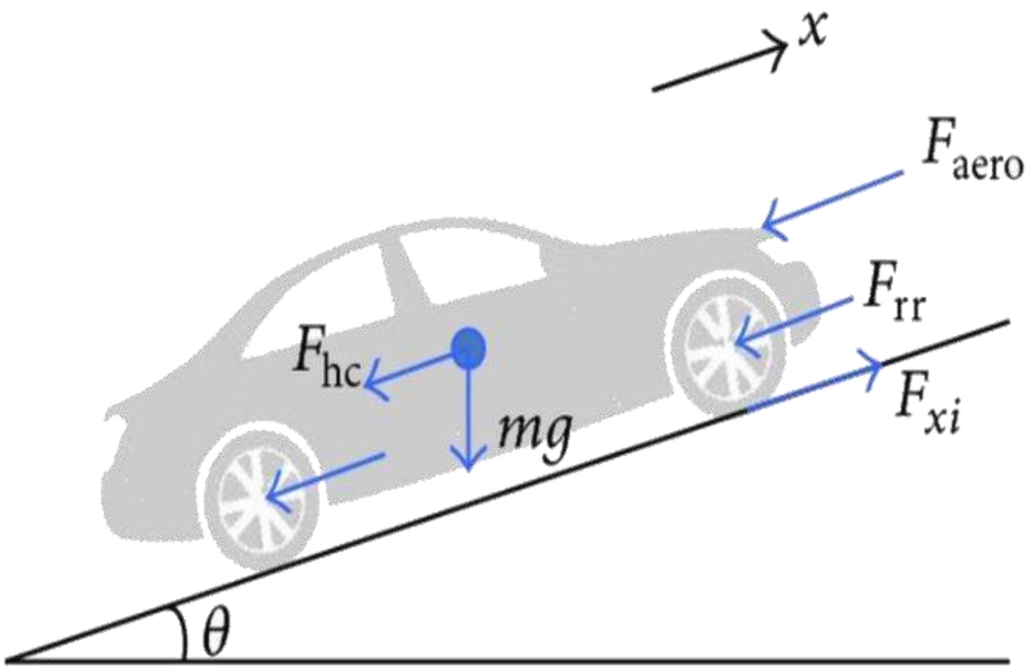


- μ_{rr} - Rolling Resistance Constant
- m - Mass of the Vehicle

FORCES ON THE VEHICLE

Total Tractive Force

1. Rolling Resistance Force(F_{rr})
2. Aerodynamic drag force(F_{aero})
3. Hill climbing Force(F_{hc})
4. Acceleration Force(F_{xi})
    1. Linear Acceleration Force
    2. Angular acceleration force



Rise / Run

F_{hc} = m.g.Sin θ

Notation	Parameters	Units	Vehicle 1				Vehicle 2			
			Value	Units			Value	Units		
m	Weight	m	**1,000.000**	Kg			1,200.000	Kg		
W	Width	W	**1.000**	m			1.000	m		
H	Hieght	H	**1.500**	m			1.500	m		
μ_{rr}	Rolling Resistance	μ_{rr}	0.020				0.020			
þ	Air Density	þ	1.250	kg/m2			1.250	kg/m2		
Cd	Drag Coefficient	Cd	0.300				0.300			
g	gravitational Force	g	9.800				9.800			
	Speed in km		**40.000**	**kpmh**			**50.000**	**kpmh**		
A	Forntal Area	A	1.500	m2			1.500	m2		
v	Velocity	v	11.111	m/sec			13.889	m/sec		
	Angle - Hill Climbing	ϴ	11.00	degree	0.192	Rad	15.000	degree	0.262	Rad

Observation:

Huge Variation in Motive power

- Vehicle is fully loaded to unloaded condition
- Vehicle in hill climbing condition
- Vehicle Speed

Acceleration of Force

The Vehicle will not be at constant speed. Dynamic equation for Acceleration force (dv/dt)

$m.dv/dt = F_t - (F_{rr} + F_{ad} + F_{hc})$

How fast can vehicle reach the top speed?

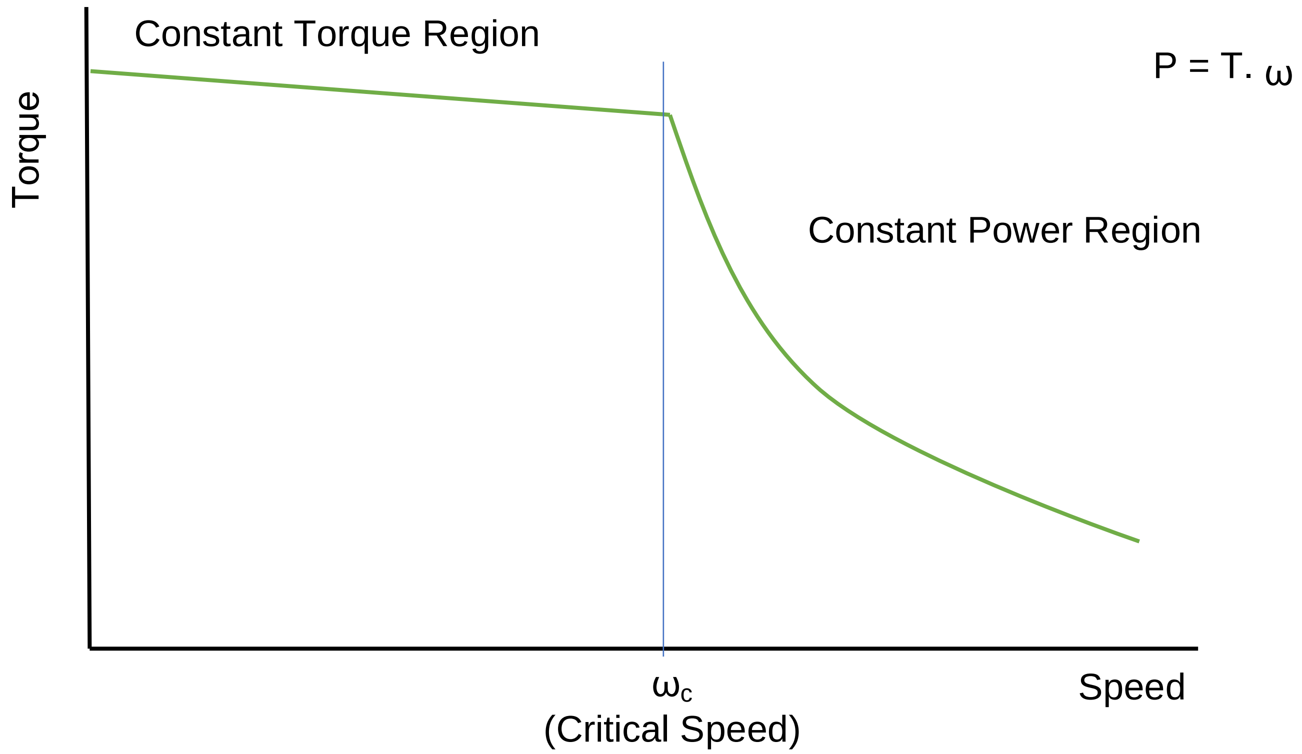
Limiting Factors I

- Weight of Vehicle
- Motor Power of Vehicle Limiting Factors II
- The Drive wheels will spin on the ground if, tractive effort>adhesive capability between tire and ground
- Significant Slipping on the ground for wet, icy, snow covered or soft soil.
- Irrespective of the maximum torque power train can apply on wheel

The vehicle is driven by motor power though gear

- $P = T . \omega$
- $\upsilon = P / (T \times 36.66)$
- $\upsilon = 12000 / (140 \times 36.66)$ m/s
- Critical Velocity = 19.8 m/s

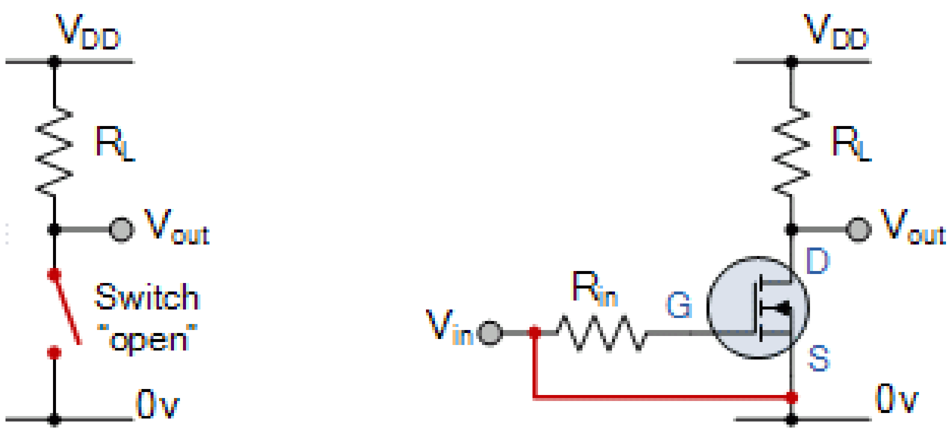
Motor Operating Region



POWER ELECTRONICS

Power electronics is the application of solid-state electronics to the control and conversion of electric power.

Ideal Switch | SCR, MOSFET, IGBT



Application of Power Electronics Converters in Electric Vehicle

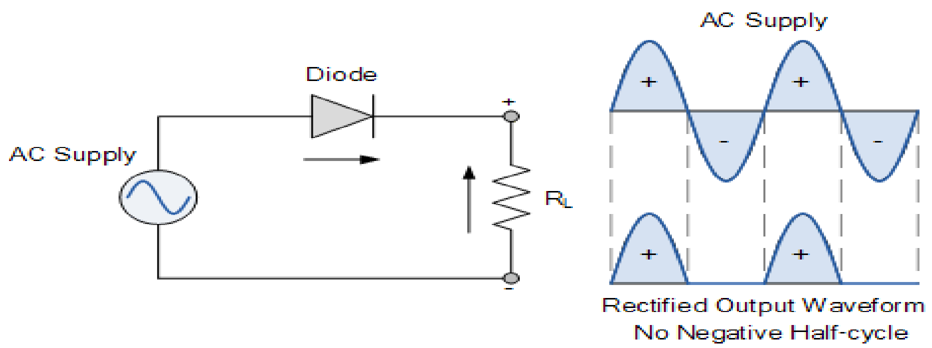
- Bidirectional Converter Topologies for Plug-In Electric Vehicles
- Bidirectional Battery Charger for an Electric Vehicle

- Bidirectional DC–DC Converter for Ultra-Capacitor Applications
- Integrated Bidirectional Converters for Plug-In HEV Applications
- Resonant Converter for a Bidirectional EV Charger
- Wireless Topology for EV Battery Charging

- Direct Conversion of an AC–DC Converter for Plug-In Hybrid Vehicles Isolated Bidirectional AC–DC Converter for a DC Distribution System
- Bidirectional T-Type Converter Topology for EV Applications
- Multilevel Two-Quadrant Converter for Regenerative Braking
- Multiphase Integrated On-board Charger for Electric Vehicles
- Split Converter-Fed Induction Motor/BLDC/SRM Drive for Flexible Charging in EV and HEV Applications

Rectifier:

- Uncontrolled Rectifier ● Controlled Rectifier
- Half wave controlled Converter
- Full wave controlled Converter
- Single Phase/Three Phase Converter



POWER CONVERTER DESIGN I

POWER CONVERTER:

Power Converters for Electric Vehicles gives an overview, topology, design, and simulation of different types of converters used in electric vehicles (EV). It covers a wide range of topics ranging from the fundamentals of EV, Hybrid EV and its stepwise approach, simulation of the proposed converters for real-time applications

Power Factor Correction (PFC)

- Power Factor Correction (PFC) shapes the input current of the power supply to be in synchronization with the mains voltage, in order to maximize the real power drawn from the mains.

- In a perfect PFC circuit, the input current follows the input voltage as a pure resistor, without any input current harmonics.

Observations:

- Power factor correction is essential to minimizing the total apparent power consumed from the grid.
- Regions around the world recognize this need and have implemented voluntary or mandatory requirements depending on the class of electronic equipment. **Design Procedure**
- Specifications
- Efficiency
- Range of Input
- % of Accuracy

$$L = \frac{1}{\%Ripple} \cdot \frac{{V_{ac.min}}^2}{P_o}\left(1 - \frac{\sqrt{2} \cdot V_{ac.min}}{V_o}\right) \cdot T$$

$$C_o \geq \frac{P_o}{2 \cdot \pi \cdot f_{line} \cdot \Delta V_o \cdot V_o}$$

Specifications:

- Power: 2KW
- Output Voltage: 400V/5A
- Efficiency : 90%
- Input Voltage regulation 15% of Input
- Op Voltage ripple 20%

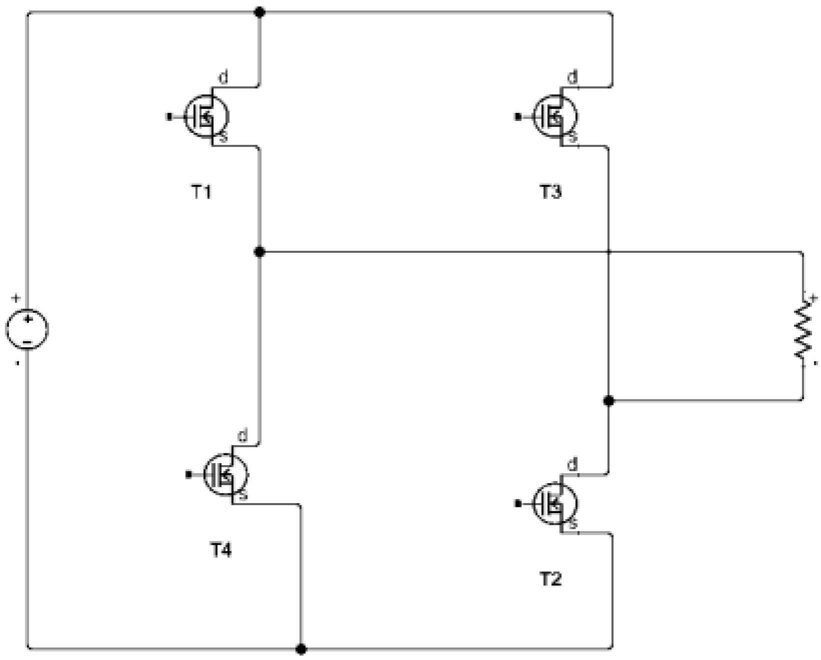
Inverter Design MATLAB Simulink

A power inverter, or inverter, is a power electronic device or circuitry that changes direct current to alternating current

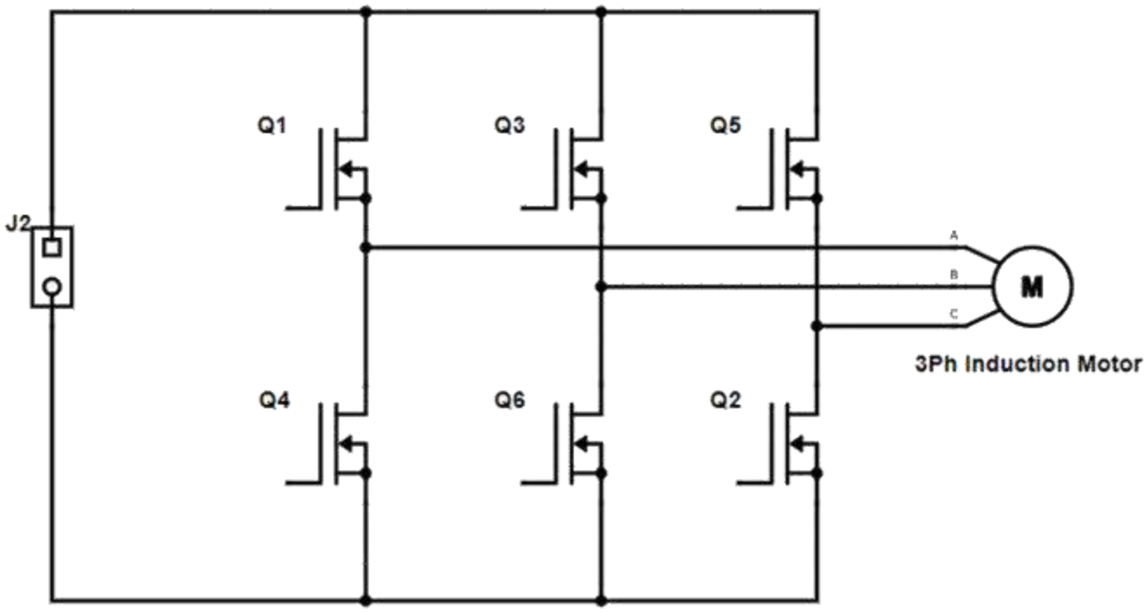
Inverter Types

Based on Load Type	output Waveform Type
1. Single phase • Half Bridge • Full Bridge 2. Three Phase • 120 Degree • 180 Degree	1. Square Wave 2. Modified sine wave 3. Pure sine wave

Single Phase Inverter



Three Phase Inverter



Working Principle

- 180 Degree Mode of Conduction
  - 3 Switches will be in "ON" Mode at a Time
  - Remaining Switches will be in "OFF" Mode
- 120 Degree Mode of Conduction
  - 2 Switches will be on ON Mode at a Time
  - Remaining Switches will be in "OFF" Mode

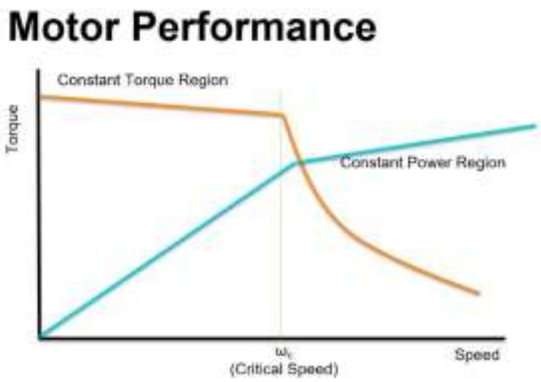
Application of Inverter

- Motor control in EV Applications
- Home Applications
- Industry Motor Control

Intro to Electric Motor for EV Application

Motors required Specification

- High efficiency
- High instant power
- Fast torque response
- High power density
- Low cost
- High acceleration
- Robustness



Motor Types:

A **synchronous electric motor** is an AC motor in which, at steady state, the rotation of the shaft is synchronized with the frequency of the supply current; the rotation period is exactly equal to an integral number of AC cycles.

An **induction motor** or asynchronous motor is an AC electric motor in which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding.

MOTORS IN EV

- Sun roof
- Sliding door
- 4WD Transfer case
- Seat adjustment
- Front wiper
- HVAC compressor pump
- Seat ventilation
- HVAC blower
- Rear wiper
- Rear camera cover
- Trunk, tail gate
- Seat belt pretension
- Window lift
- Power Train Motor

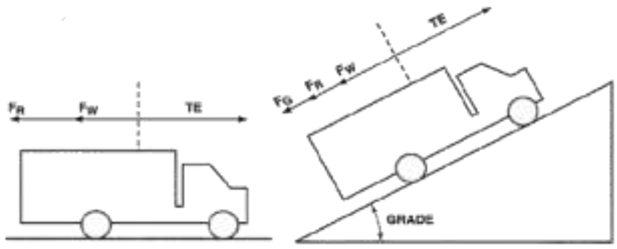
PURPOSE OF CONTROLLER

- Starting

- Stopping
- Reversing
- Running
- Speed Control
- Safety of Operator
- Protection from Damage

10 Factors to choose Electric Motors for EV

- Driving cycles
- Vehicle characteristics
- Vehicle configuration (electric, hybrid)
- Maximal speed
- Maximal torque
- Maximal power
- Battery Capacity ● Battery Voltage
- Gearbox or direct-drive?
- Cost



Top 10 Best Electric Motorcycles in world

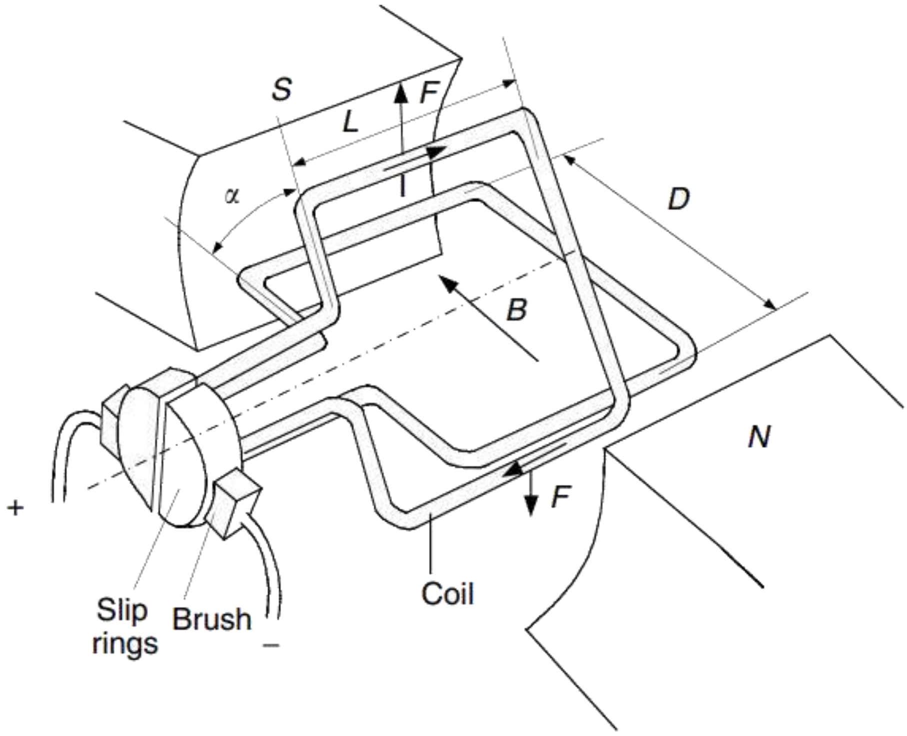
- Harley-Davidson LiveWire
- Zero SR
- Energica Ego

- Brutus V9
- Johammer J1.200
- Tacita T-Race Diabolika
- Damon Hypersport Premier
- Vespa Elettrica
- Gogoro Smartscooter S2 Adventure
- Honda PCX ELECTRIC

Top 10 best luxury electric cars 2021

1. Mercedes-Benz EQC
2. Jaguar I-Pace
3. Ford Mustang Mach-E
4. Tesla Model S
5. Tesla Model 3
6. Polestar 2
7. Audi E-tron Quattro
8. BMW iX3
9. Tesla Model X
10. Lexus UX 300e

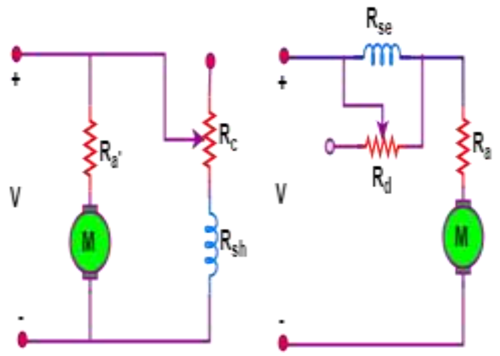
DC Motor Speed Control

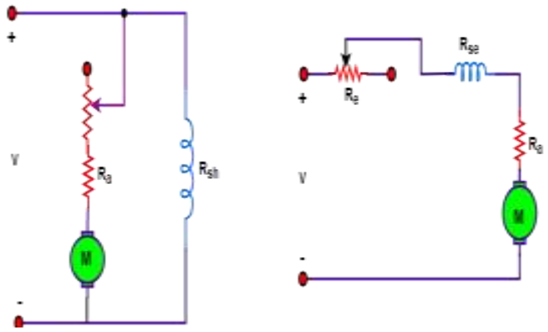


- When a wire carrying electric current is placed in a magnetic field, a magnetic force acting on the wire is produced.
- The force is perpendicular to the wire and the magnetic field.
- The magnetic force is proportional to the wire length, magnitude of the electric current, and the density of the magnetic field

Magnetic Force $F = BIL$
Torque $T = BIL\ Cos\alpha$

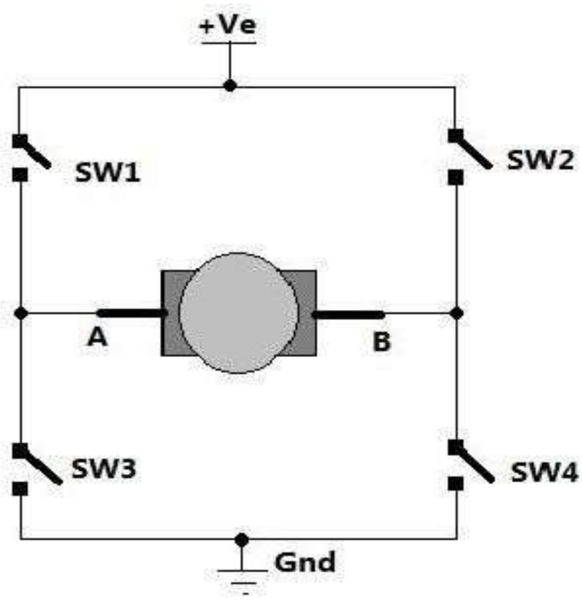
$\alpha -$ angle between the coil plane and magnetic field F= Force, B = magnetic flux density, I = current





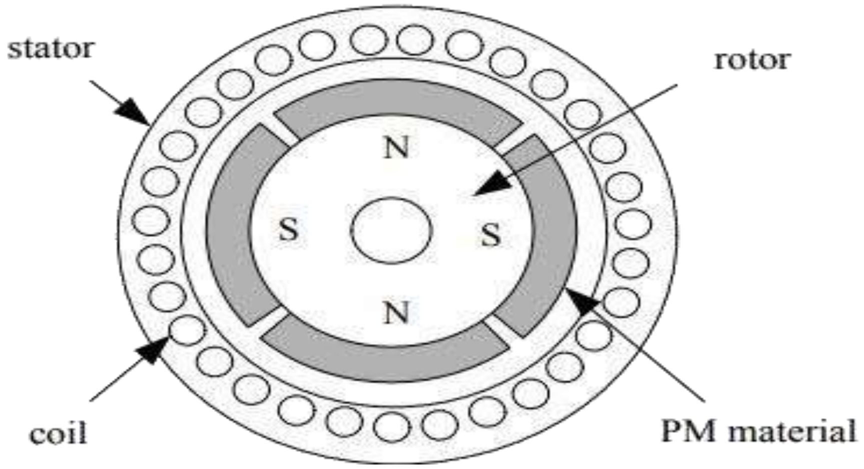
Flux Control **Armature & Rheostat Control**

SPEED CONTROL:



ADVANTAGES	DISADVANTAGES
• High Torque • Simple Control • Low Cost	• High Maintenance cost • Poor Efficiency

BLDC Motor Speed Control



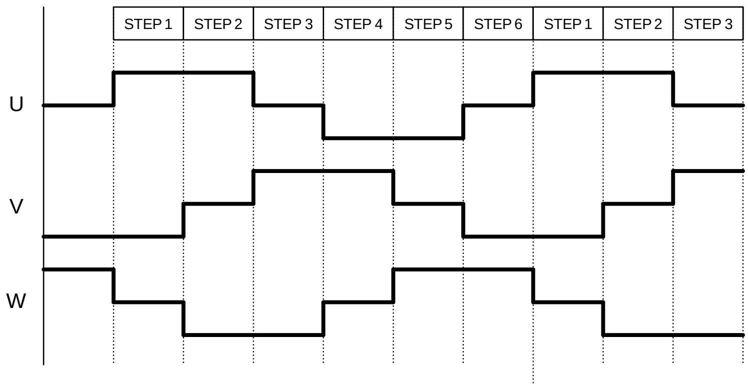
Brushed DC Commutation

- The windings in the armature are switched to the DC power by the brushes and armature
- Each winding sees a positive voltage, then a disconnect, then a negative voltage
- The field produced in the armature interacts with the stationary magnet, producing torque and rotation

DC Motor Bridge

- The DC motor needs four transistors to operate the DC motor
- The combination of transistor is called an H-Bridge, due to the obvious shape
- Transistors are switched diagonally to allow DC current to flow in the motor in either direction
- The transistors can be Pulse Width Modulated to reduce the average voltage at the motor.

Three-Phase Bridge to Drive BLDC Motor

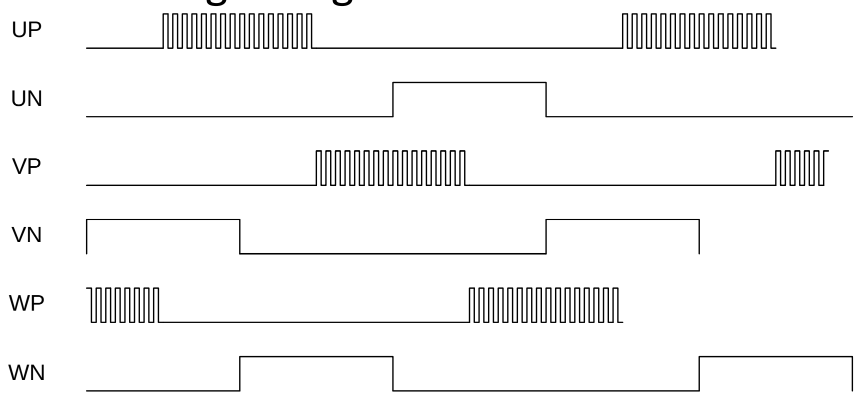


Six-step Commutation

- The Brushless DC motor is really a DC motor constructed inside-out, but without the Brushes and Commutators
- The mechanical switches are replaced with transistors
- The windings are moved from the armature, to the stator
- The magnet is moved from the outside to become the rotor

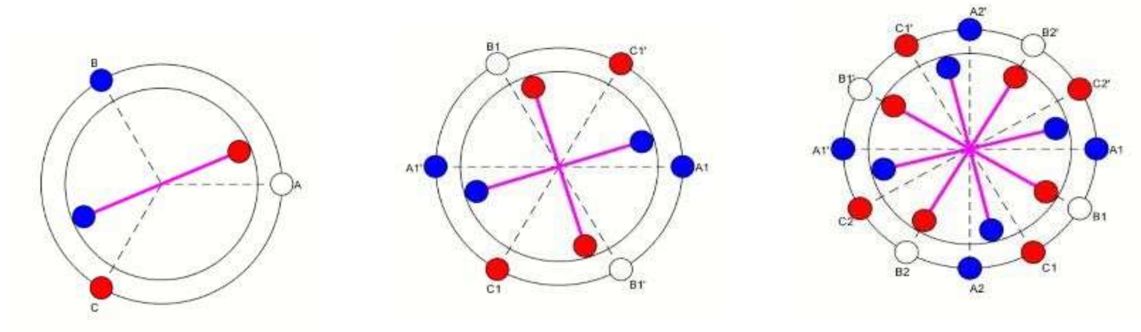
3-Phase PWM:

We can divide up the phase data into individual transistor gate signals

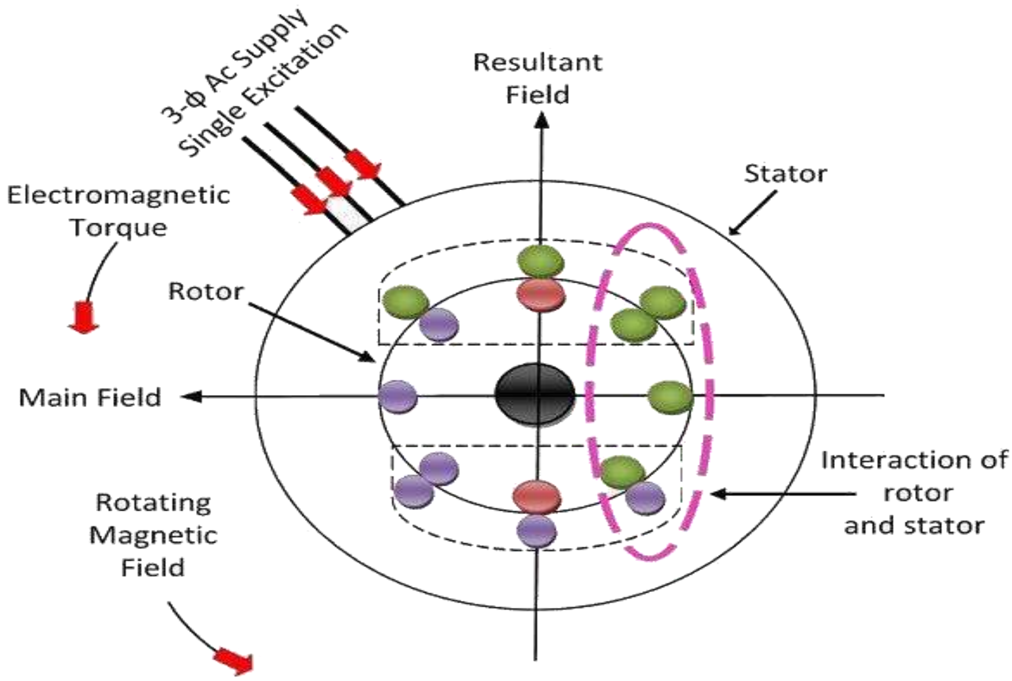


Types of BLDC Motor based on Magnet Arrangement

1. One Pole Pair
2. Two Pole Pair
3. Four Pole Pair



Induction Motor Speed Control



AC Motor

Asynchronous Motor & Synchronous Motor

Three Phase
Single Phase
Wound Rotor
Squirrel Cage

Speed Control Methods
(Note: For Squirrel Cage Motors)

$$N_s = \frac{120f}{P}$$

$$E \; or \; V = 4.44\phi K.T.f \; or \; \phi = \frac{V}{4.44KTf}$$

Variable Frequency Variable Voltage

Advantages:

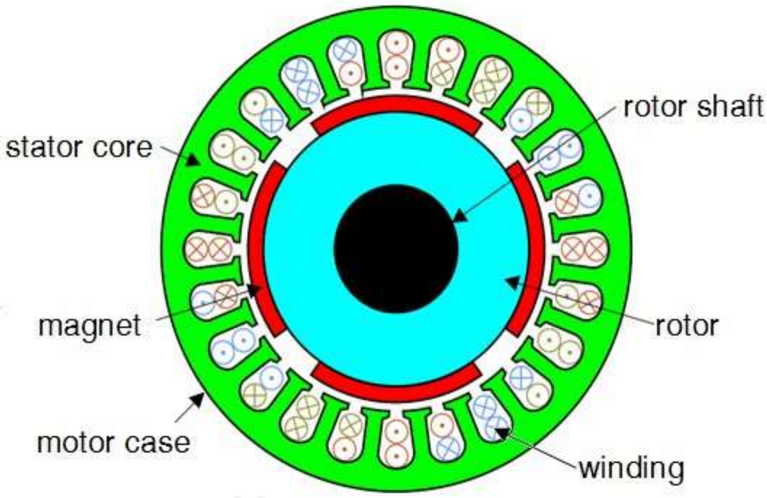
- Simple and rough construction
- Affordable and low maintenance
- High reliability and highly proficient
- No requirement of additional starting motor and necessity not be synchronized

Applications:

- Large capacity exhaust fans
- Driving lathe machines
- Oil extracting mills
- Electric Sewing Machine
- Drilling machines

PMSM Speed Control

Permanent Magnet Synchronous Motors (PMSM) are similar to Brushless DC motors (BLDC). PMSM are rotating electrical machines that have a wound stator and permanent magnet rotors that provide sinusoidal flux distribution in the air gap, making the BEMF inform a sinusoidal shape.

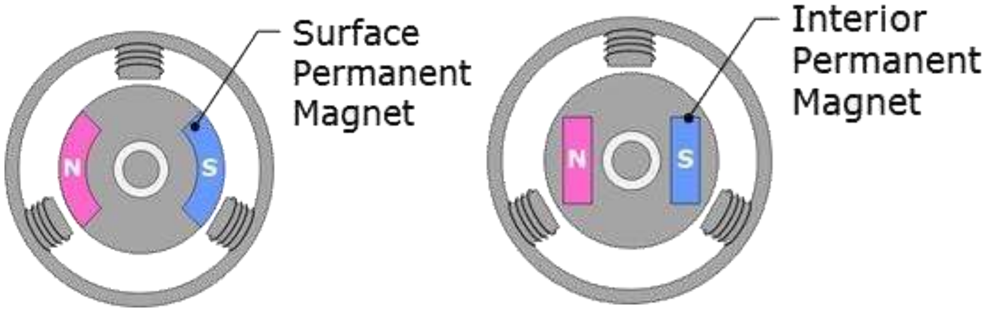


PMSM Structure

BLDC	PMSM
• DC Power • Square Flux Density • Trapezoidal Back EMF • Stator Current is Trapezoidal • Controlling is easy and Cheaper	• AC Power • Sinusoidal Flux Density • Sinusoidal Back EMF • Stator Current is Sinusoidal • Quite Complex and costly

Classification of PMSM with the Rotor Design

- Surface Mount PMSM
- Interior Mount PMSM



PMSM Characteristics

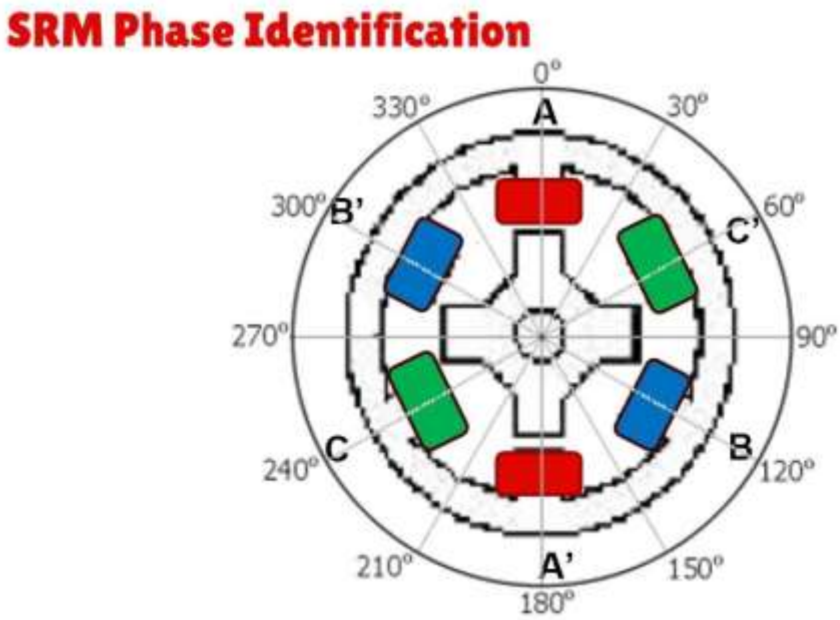
- No sparks, safer in explosive environments
- Clean, fast and efficient
- Designed for high-performance servo applications
- Runs with/without position encoders

Applications

1. AC Drives
2. Automated Guided Vehicles
3. Heating, ventilation and air conditioning
4. Robots
5. Servo drives

Switched Reluctance Motor Speed Control

- 1830-1850 SRM Concept Evolved
- Due to Tesla Invented AC Induction Motor in Late 1800's, the entire market diverted
- Technology development in Power Electronic Circuit, the SRM again capture the Market (1960s)



SR Drive:

6/4 Pole Switched Reluctance Motor

- Converter Design
- Gate Pulse Generation
- Current Control

Battery For EV Application

Types of EV Battery

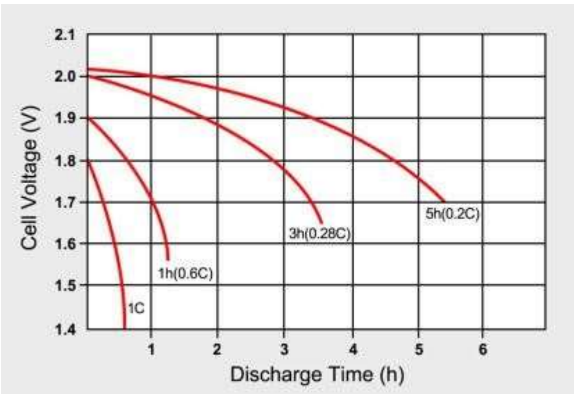
- Lithium-ion
- Lithium Phosphate
- Nickel-metal hydride batteries
- Lead-acid batteries

Model	Battery	Charge Times
Toyota Prius PHEV	4.4kWh Li-ion, 18km all-electric range	1.5h at 230VAC 15A
Chevy Volt PHEV	16kWh, Li-manganese/NMC, liquid cooled, 181kg (400 lb), all electric range 64km	4h at 230VAC, 15A
Mitsubishi iMiEV	16kWh; 88 cells, 4-cell modules; Li-ion; 109Wh/kg; 330V, range 128km	7h at 230VAC 15A
Smart Fortwo ED	16.5kWh; 18650 Li-ion, driving range 136km	3.5h at 230VAC, 15A
BMW i3 Curb 1,365kg	Since 2019: 42kWh, LMO/NMC, large 60A prismatic cells, battery weighs ~270kg (595 lb) driving range: EPA 246 (154 mi); NEDC 345km (215 mi); WLTP 285 (178 mi)	11kW on-board AC charger; ~4h charge; 50kW DC charge; 30 min charge.
Nissan Leaf*	30kWh; Li-manganese, 192 cells; air cooled; 272kg, driving range up to 250km	8h at 230VAC, 15A; 4h at 230VAC, 30A
Tesla S* Curb 2,100kg (4,630 lb)	70kWh and 90kWh, 18650 NCA cells of 3.4Ah; liquid cooled; 90kWh pack has 7,616 cells; battery weighs 540kg (1,200 lb); S 85 has up to 424km range	9h with 10kW charger; 120kW Supercharger, 80% charge in 30 min
Tesla 3 Curb 1,872 kg (4072 lb)	Since 2018, 75kWh battery, driving range 496km ; 346hp engine, energy consumption 15kWh /100km (24kWh/mi)	11.5kW on-board AC charger; DC charge 30 min
Chevy Bolt Curb 1,616kg; battery 440kg	60kWh; 288 cells in 96s3p format, EPA driving rate 383km; liquid cooled; 200hp electric motor (150kW)	10h at 230VAC, 30A 1h with 50kWh
MG EV ZS	44.5KW Lithium Ion	394V

Battery Parameters

Battery SoC: The fraction of the total energy or battery capacity that has been used over the total available from the battery

Shows the remaining capacity of the battery while in use



Battery Calculations

Step #1 Current Consumption by Motor

P = V x I

I = 10KW/72V

Current required to run full load by the Motor - 139 Amps

<u>Step #2</u> Watt-Hour Calculation Assume

Running Time 1 Hour

P = 10000 x 1 Watt -Hour

<u>Step #3</u> Ampere Hour Calculation

The Source must have 20-30% more than the required energy

Assume : 20%

Watt-Hour = 10000 x 1.2 = 12000

Ampere Hour = Watt-Hour /Battery Terminal Voltage

= 12000/72

= 166.67Ah

Battery Rating *72V, 166.67Ah*

<u>SoC Estimation</u>

State of charge (SOC) is a relative measure of the amount of energy stored in a battery, defined as the ratio between the amount of charge extractable from the cell at a specific point in time and the total capacity

SoC = <u>Capacity Remaining</u>

Total Capacity

$$SoC(t) = \frac{1}{C}\int_0^t I(t)\,dt$$

$$SoC(t) = SoC(t-1) + \frac{1}{C}\int^t I(t)\,dt$$

$SoC(t-1)$ ……… Initial SoC

I(t) ………………… Battery Current at time Instant *dt*

…………………. Step Time

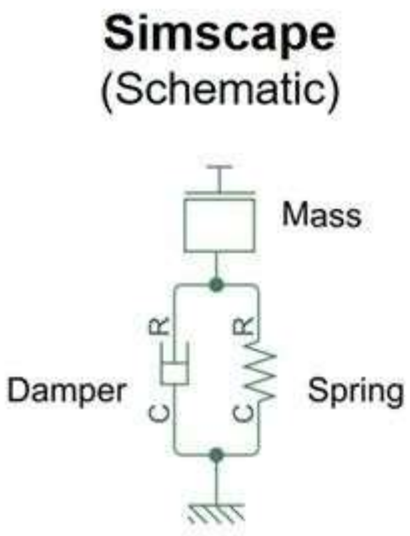
C ………………….. Nominal Capacity of Battery in Ah

Methods to Estimate SoC

- Coulomb Counting
- Kalman Filter
- Extended Kalman Filter

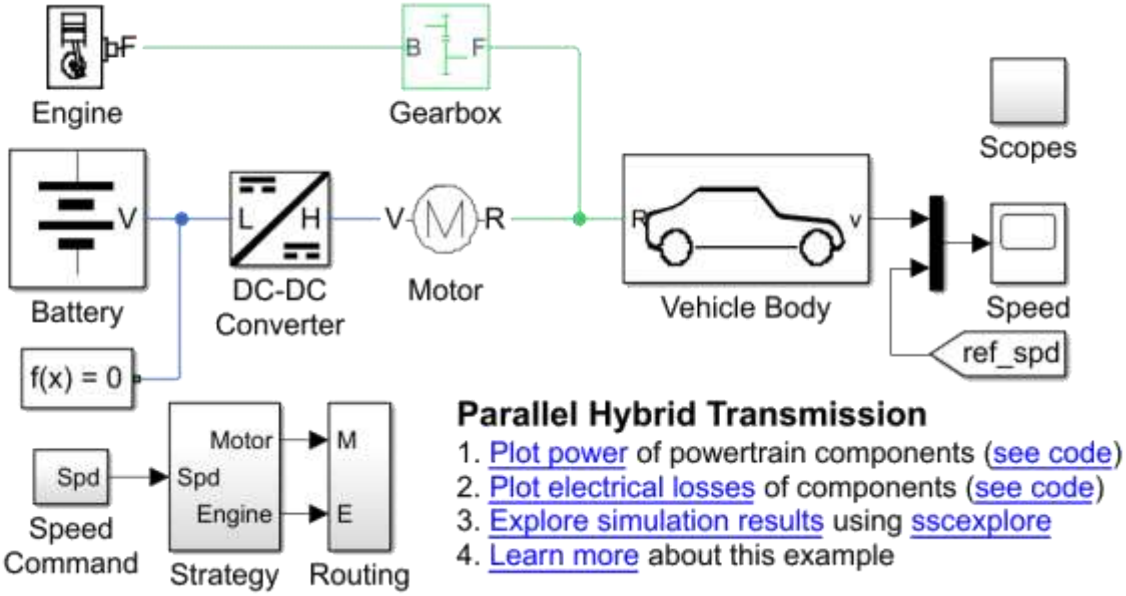
Simscape Introduction

To create models of physical systems within the Simulink® environment.



- Modeling and simulating multidomain physical systems
- Elements for various physical domains

- unit manager, data logging etc



<u>Simscape Fundamental</u>

Understanding the Physical Variables

Energy Flow = Across X Through Sensors in Parallel X Sensor in Series

Electrical Domain Power = Voltage (V) X Current (Amps)

Mechanical Rotational Domain

Power = Angular Velocity (rad/sec) X Torque (Nm)

Rules Governing Physical Variables

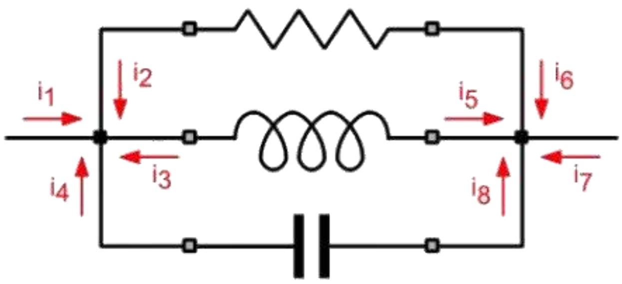
Kirchhoff's Current Law $\sum^{4}_{r=1} ir = \sum^{8}_{r=5} ir = 0$

Kirchhoff's Voltage Law 0 = V_{-DC}

$V_{+DC} = V_{-R}\ V_{+R}$

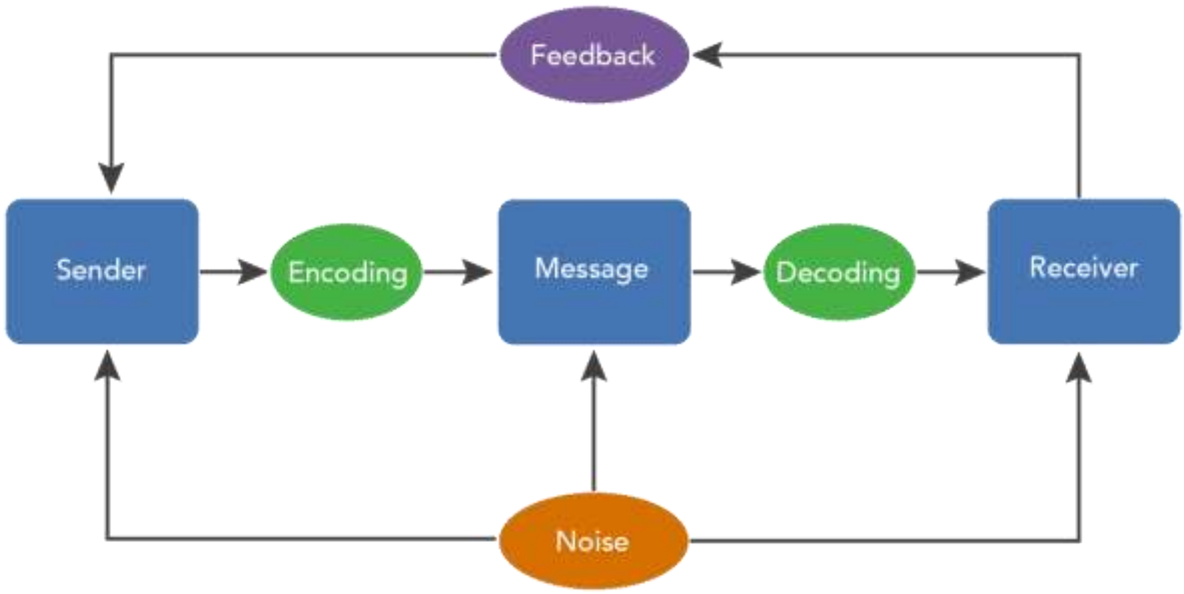
$= V_{-C}$

$V_{+C} = 0$



Protocols for EVs

PROTOCOL: It's an agreement about how to do something



Communication:

- Fault tolerance
- Determinism
- Bandwidth
- Flexibility
- Security

Types of Protocols

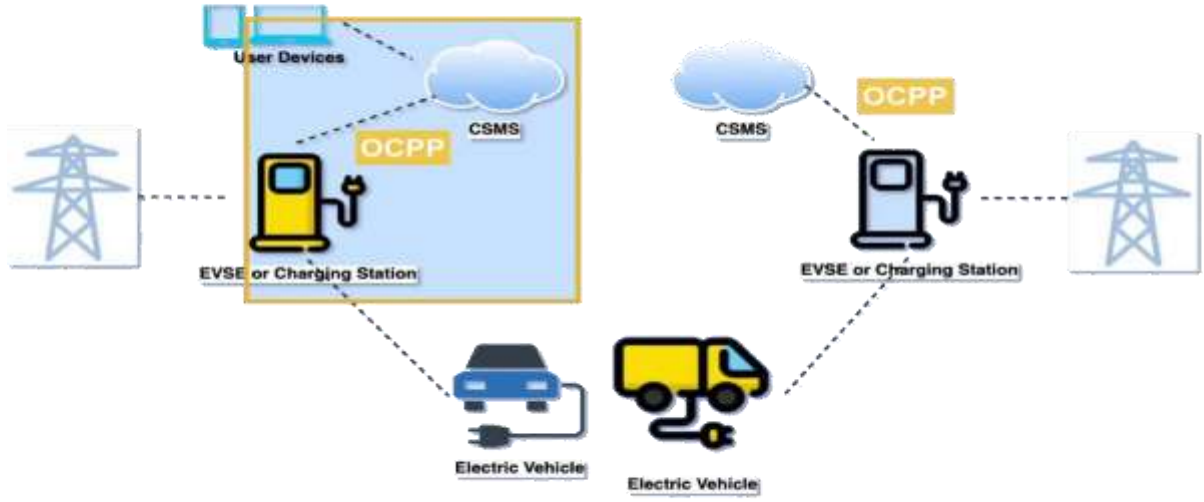
- Data Link Protocols (UART/SPI/IIC/LIN/CAN)
- Application Protocols (UDS/J1939/CAN-Open/MOST)
- Others (Bluetooth/Wi-Fi/USB/4G/5G)

How to select new protocol for a new feature?

- Max Payload Size
- Network Bandwidth ex Max Speed of Data Transmission
- Max Bus Length Supported
- Architecture (Master/Slave Configuration Options)
- Transfer Model (Full/Half duplex & synchronous/asynchronous)
- Fault Tolerance
- Suitablity for safty critical feature
- Ease of addition removal into/from the vehicle network design

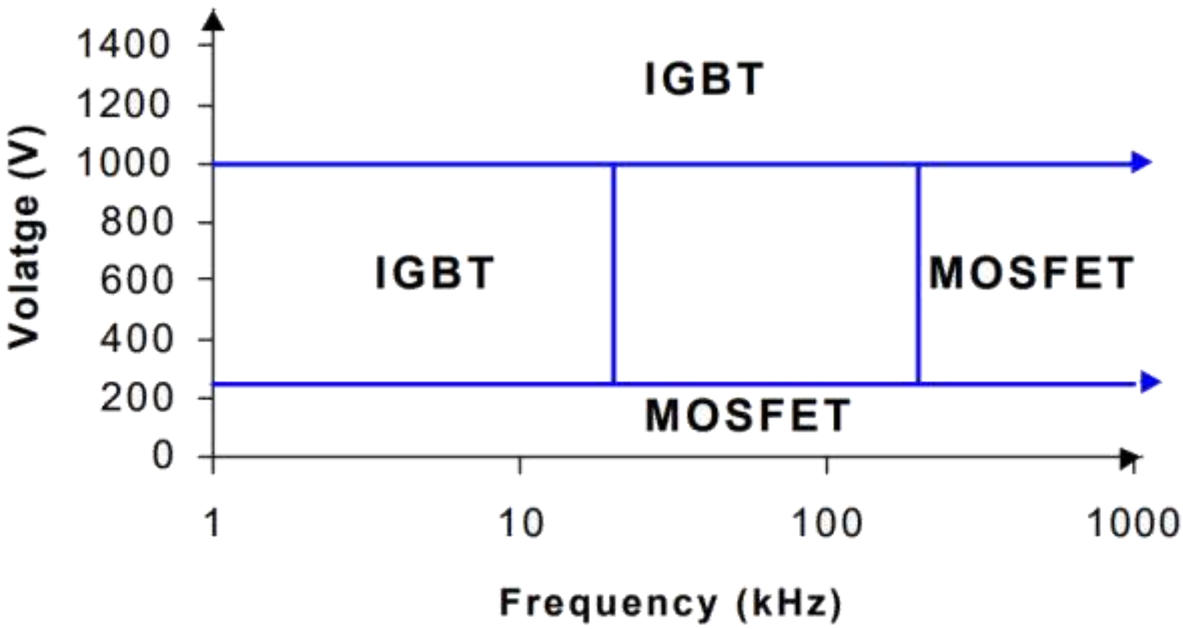
Protocols for EV Charging Industry

EV charging industry standards and protocols which deliver the flexibility that is needed for the entire electric vehicle market and will be a key enabler of future EV charging infrastructure developments.



<u>Gate Driver Design for MOSFET/IGBT</u>

How to Choose Device

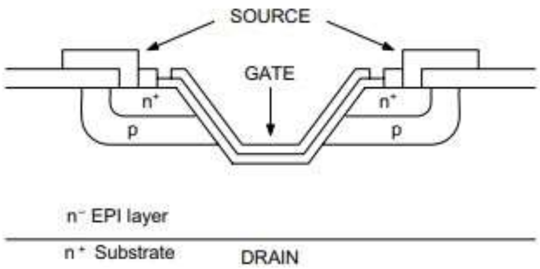


GATE Driver Properties

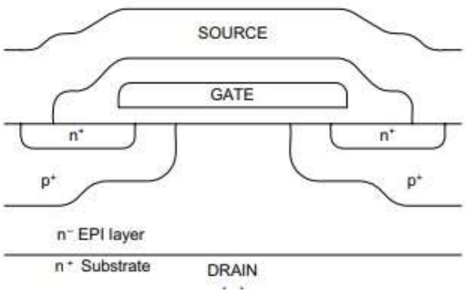
1. Isolator
2. Amplifier Gate Current Calculation
3. Speed up Mechanism(Turn ON/OFF)
4. Driver Peak Current
5. Fast short-circuit protection,

6. Active Miller clamp,
7. Shoot-through protection,
8. Fault, Shutdown, and over current protection

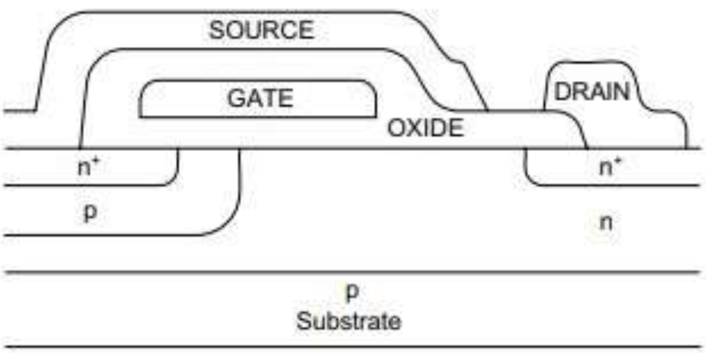
Structure of MOSFET Technology



V-groove or trench technology to further increase cell density in power MOSFET devices.
The better performance and denser integration do not come free; however, as trench MOS devices are more difficult to manufacture.



Using polycrystalline silicon gate structures and self-aligning processes, higher density integration and rapid reduction in capacitances became possible



EV Model Fabrication Design

Hardware Design of EV

Step#1 Specification

Step#2 Vehicle Structure

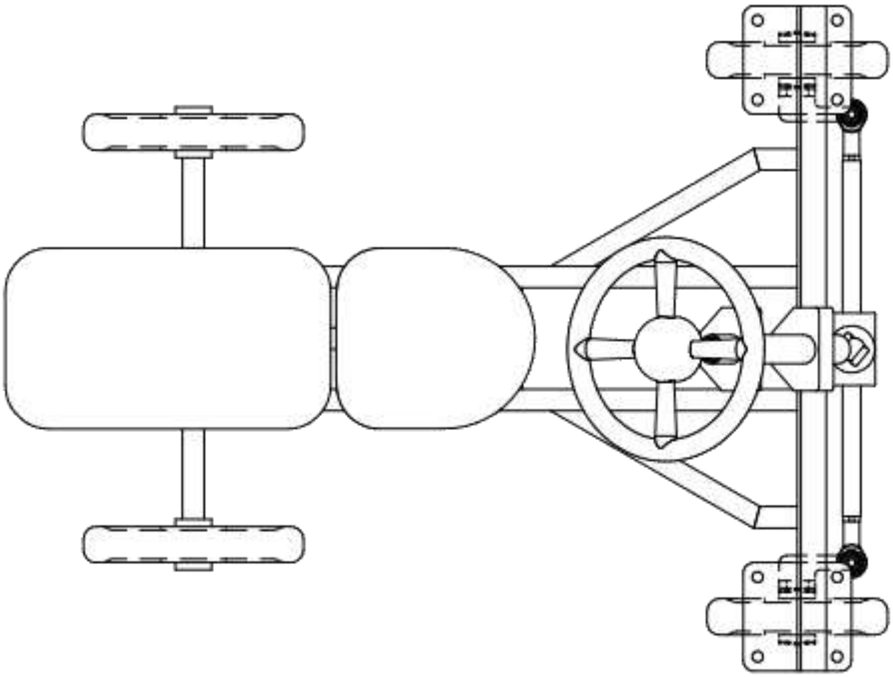
Step#3 Motor Selection

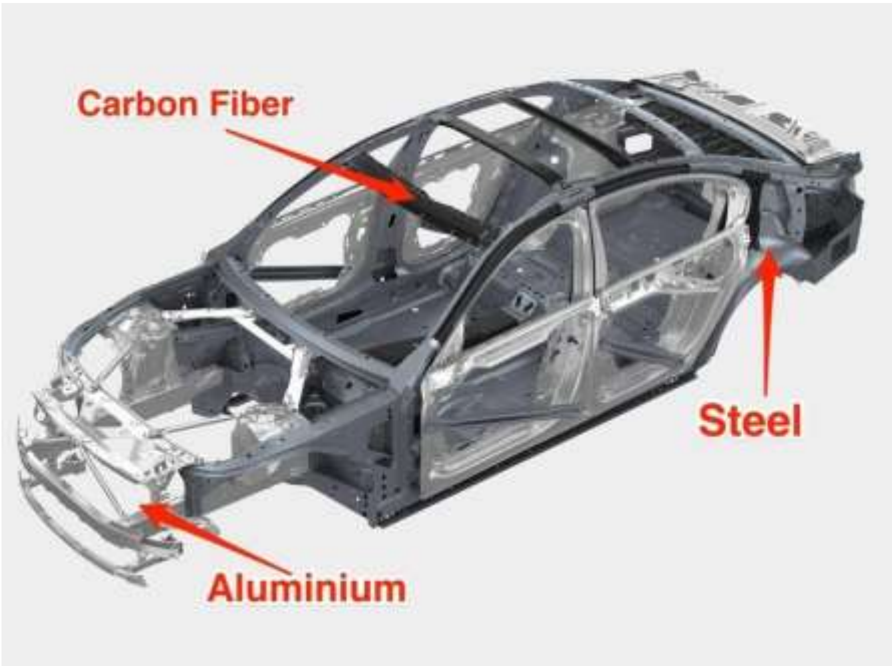
Step#4 Controller Design

1) Specification

Notation	Parameters	Units	Vehicle Value	Units
m	Weight	m	140.000	Kg
L	Length	L	0.900	m
W	Width	W	0.500	m
μ_{rr}	Rolling Resistance	μ_{rr}	0.050	
þ	Air Density	þ	1.250	kg/m2
Cd	Drag Coefficient	Cd	1.200	
g	gravitational Force	g	9.800	
	Speed in km		20.000	kpmh
A	Forntal Area	A	0.450	m2
v	Velocity	v	5.556	m/sec
	Rolliong Resistance Force		68.600	Watts
	Aerodynamic Drag Force		10.417	Watts
	Hill Climbing Force		-	Watts
F_{te}	Tractive Force	F_{te}	79.017	$F_{RR}+F_{ad}$
	Total Power for 20Km	F_{te}	438.981	Watts

2) Vehicle Structure





3) Motor Selection Motors required Specification

- High efficiency
- High instant power
- Fast torque response
- High power density
- Low cost

- High acceleration
- Robustness

- **Motor Specification**
- Rated Power: 360W
- Output Speed: 250rpm
- Motor Length: 330mm
- Rated Voltage: 24V

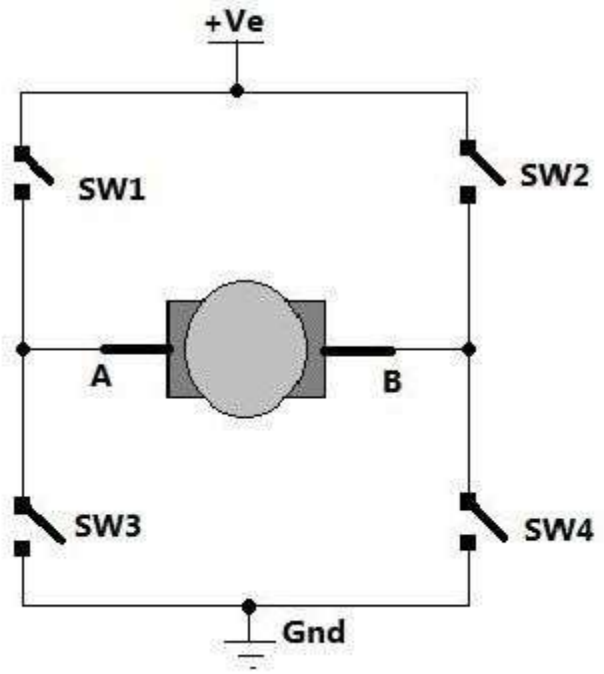
- **Motors for EV**
- DC Motor
- AC Induction Motor
- PMBLDC
- PMSM ● SRM

4) Controller Design

- Motor Type: PMDC Motor
- Operation: 4 Quadrant
- Motor Speed 0-100rpm
- Vehicle Speed: 0-20/25 kmph
- Break: Regenerative Brake
- Controller: Arduino Mega

Power Supply Requirements

- Motor Power Supply (Battery: 24V)
- Gate Driver Power Supply (15V DC)
- Arduino Power Supply (5 V DC)



SCOPE OF ELECTRIC VEHICLE

Automakers from all around the world are sighting a keen eye on Indian markets. With world's largest electric vehicle manufacturer, Tesla coming into to the Indian electric automotive spectrum, it is not futile to say that India got a new lease for becoming the future hub for electric vehicles. However, the pandemic has slowed the growth speed of India by leaps and bounds.

In April 2019, NITI Aayog, the federal think tank, published a report titled "India's Electric Mobility Transformation", which pegs EV sales penetration in India at **70 percent for**

commercial cars, 30 percent for private cars, 40 percent for buses, and 80 percent for two- and three- wheelers by 2030.

As electric vehicle manufacturing is becoming popular every day, its market share is also expected to rise greatly. India's GDP is expected to grow by an amazing 25% by 2022. The best part is that, apart from reducing environmental pollution, EVs **can lower oil import by about $60 Billion by 2030**.

Source india-briefing.com

CONCLUSION

The global electric vehicle market size is projected to grow from 4,093 thousand units in 2021 to 34,756 thousand units by 2030, at a CAGR of 26.8%. India has already shown its keen interest to be a major part of this automotive paradigm shift.
Countries like, The UK, France, Norway and Germany have even brought in legislation to ban the sales of non-electric vehicles as early as 2025.

India has already shown its keen interest to be a major part of this automotive paradigm shift. Adding to that, India has already put forward the desire to become the biggest hub for electric vehicles in the future.

Price of electricity as fuel could fall as low as Rs 1.1/km, helping an electric vehicle owner save up to Rs. 20,000 for every 5,000km traversed.

Finally, electrification will help reduce vehicular emissions, a key contributor to air pollution which causes an average 3% GDP loss every year, reports suggest.

REFERENCES:

MATLAB SIMULATION FILES

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