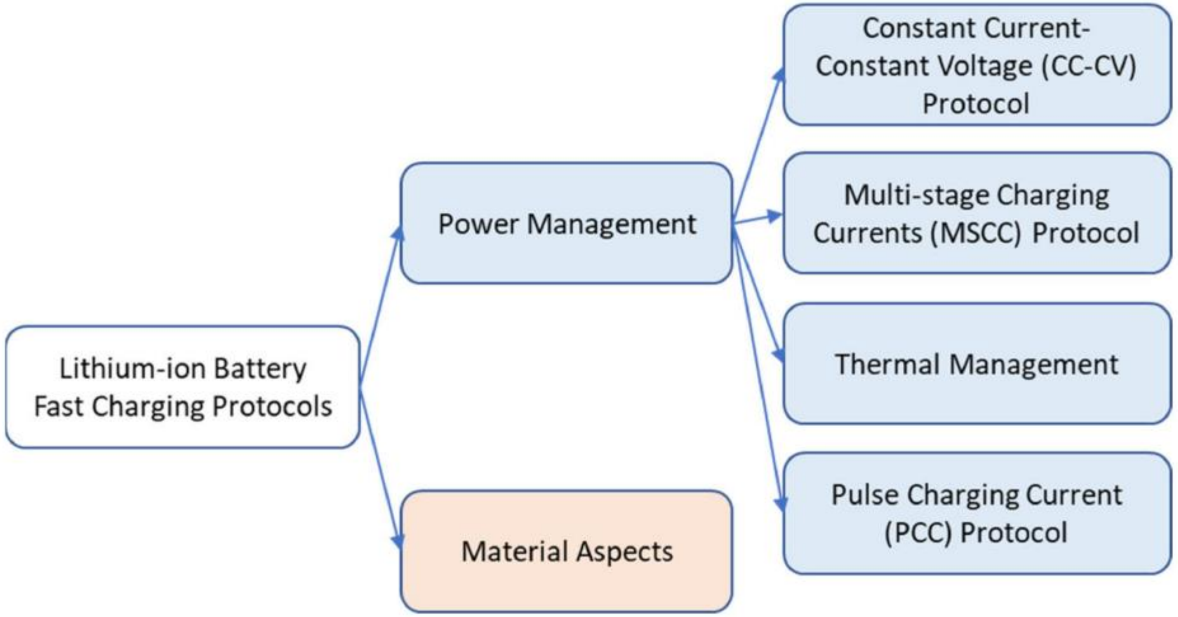
# Electric Vehicle (EE60082)

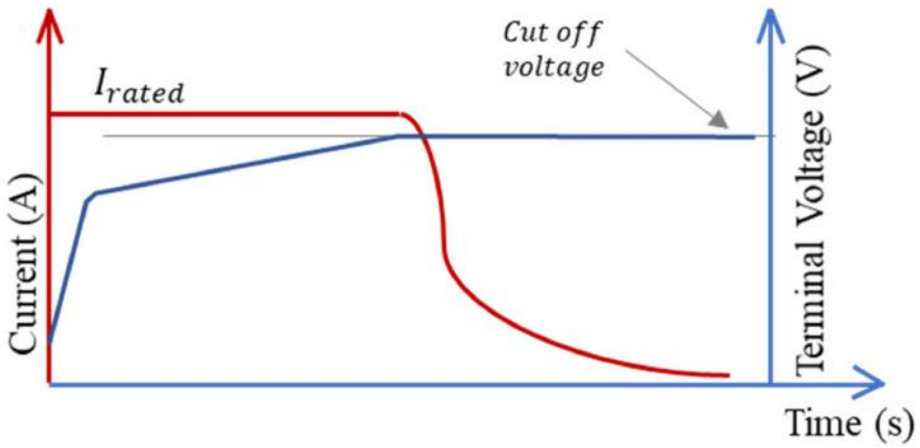
*Lecture 19: Auxiliary Power Module*

DR. SHIMUL K. DAM

ASSISTANT PROFESSOR,
DEPARTMENT OF ELECTRICAL ENGINEERING,
INDIAN INSTITUTE OF TECHNOLOGY (IIT), KHARAGPUR.

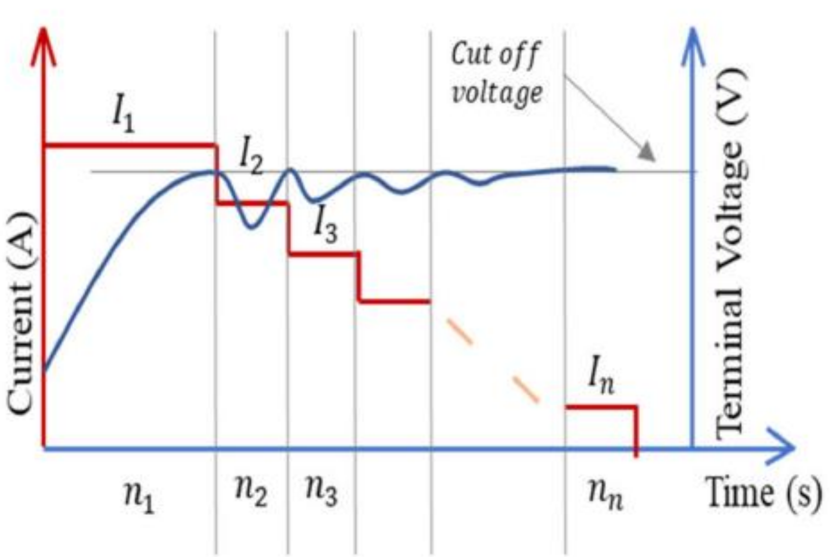
# Charging protocols (recap)



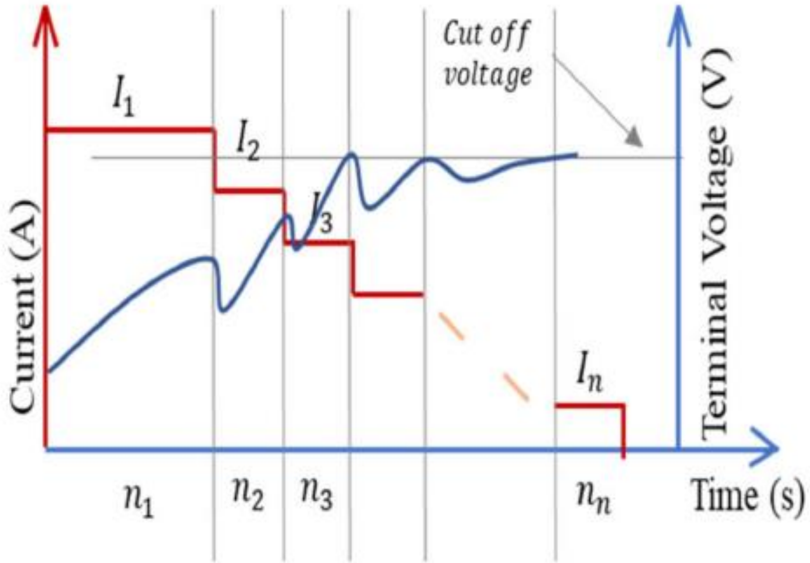




- CC-CV method:
  - Simple, effective, and popular
  - Long CV mode
  - Possibility of degradation from over-voltage

# Multi-stage charging current protocol (recap)



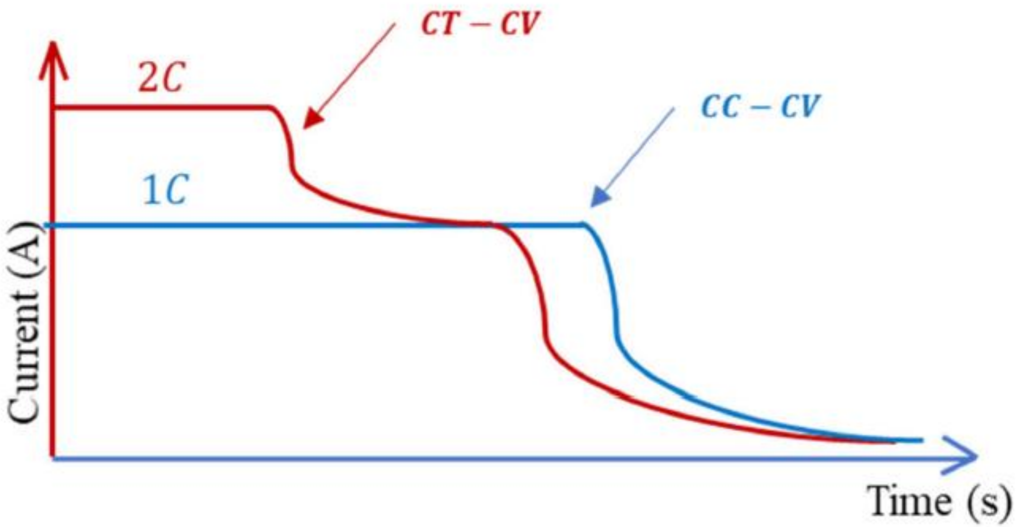

Fixed cut-off voltage technique




Hierarchical cut-off voltage technique

- MSCC method:
  - Many charging pattern possible
  - Optimization to be carried out for specific cell design and environmental conditions
  - Faster charging possible to reduce total charging time

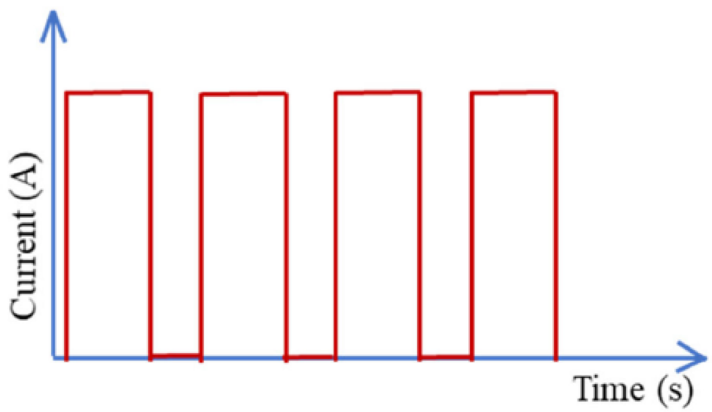
# Thermal management protocol (recap)



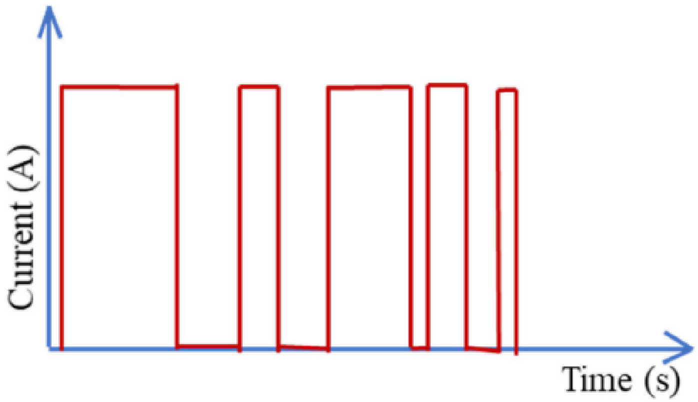

CT-CV protocol

- Constant temperature constant voltage (CT-CV) protocol:
  - Fast charging till temperature cut-off is reached
  - CV mode follows
  - Faster charging possible to reduce total charging time
  - Safer charging

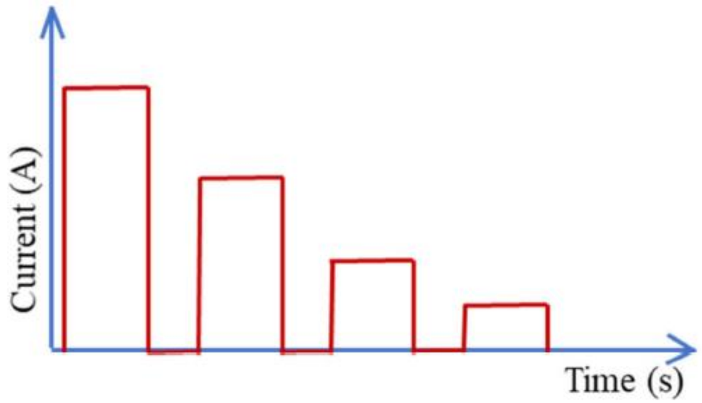
# Pulse charging current (PCC) protocol (recap)



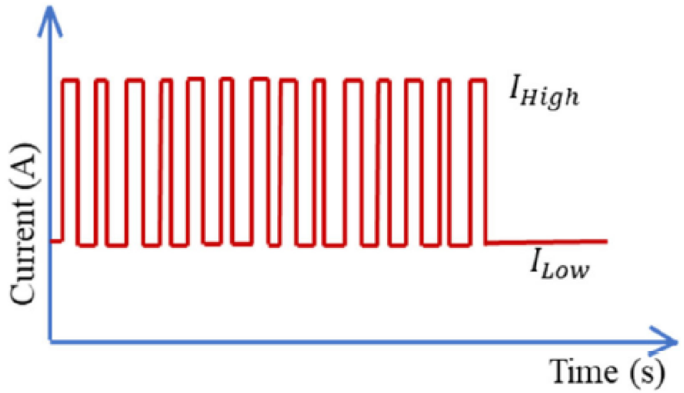
Equal duty protocol



Variable duty protocol



Decaying current protocol



Upper and lower current limit protocol

- PCC protocol:

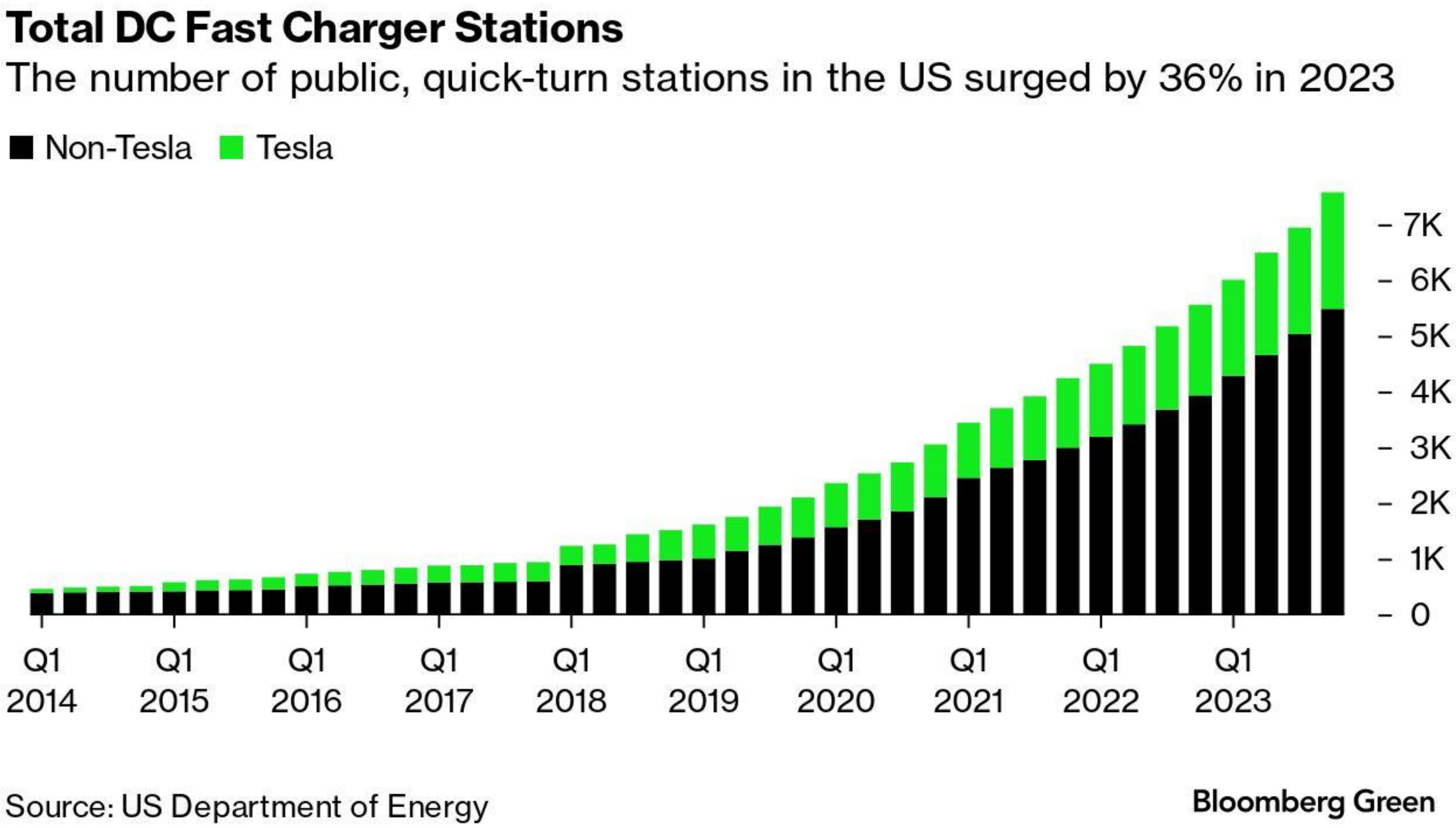
Pros:

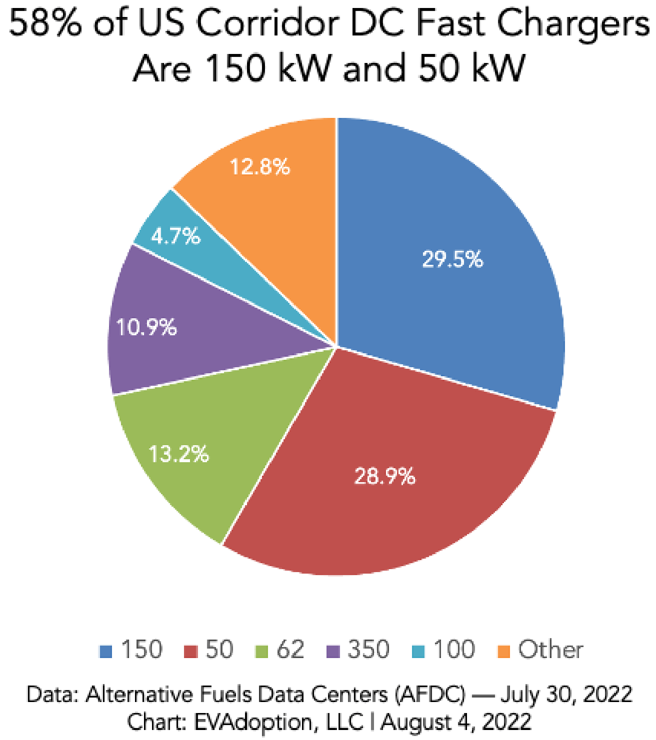
- Rest between current pulses
- Helps in diffusion of ions
- Reduction in diffusion resistance

Cons:

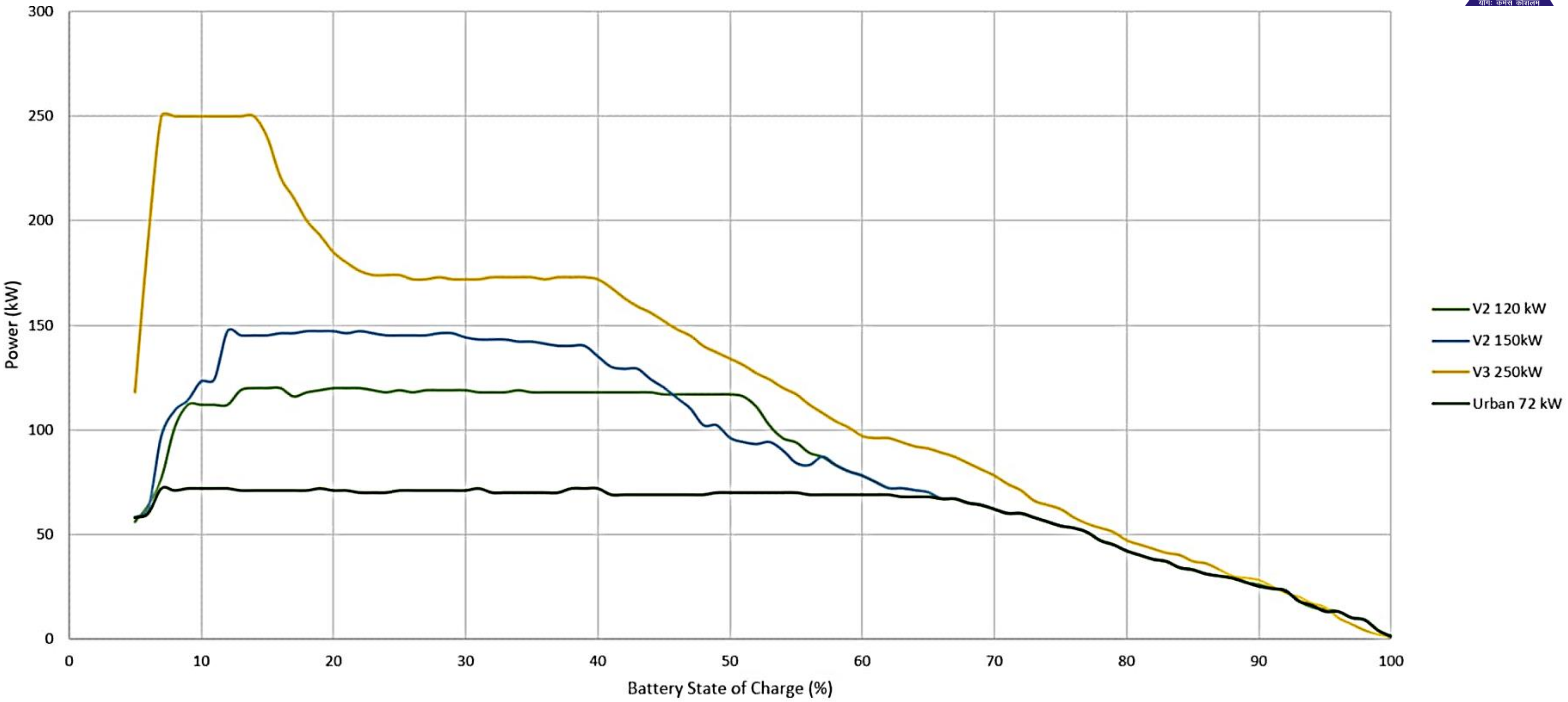
- Cost and complexity of charger increases
- Marginal benefits for a large battery pack
- Stress on power grid
- May have adverse impact on battery life

# DC fast charging in USA (recap)



# Performances of Tesla superchargers (recap)



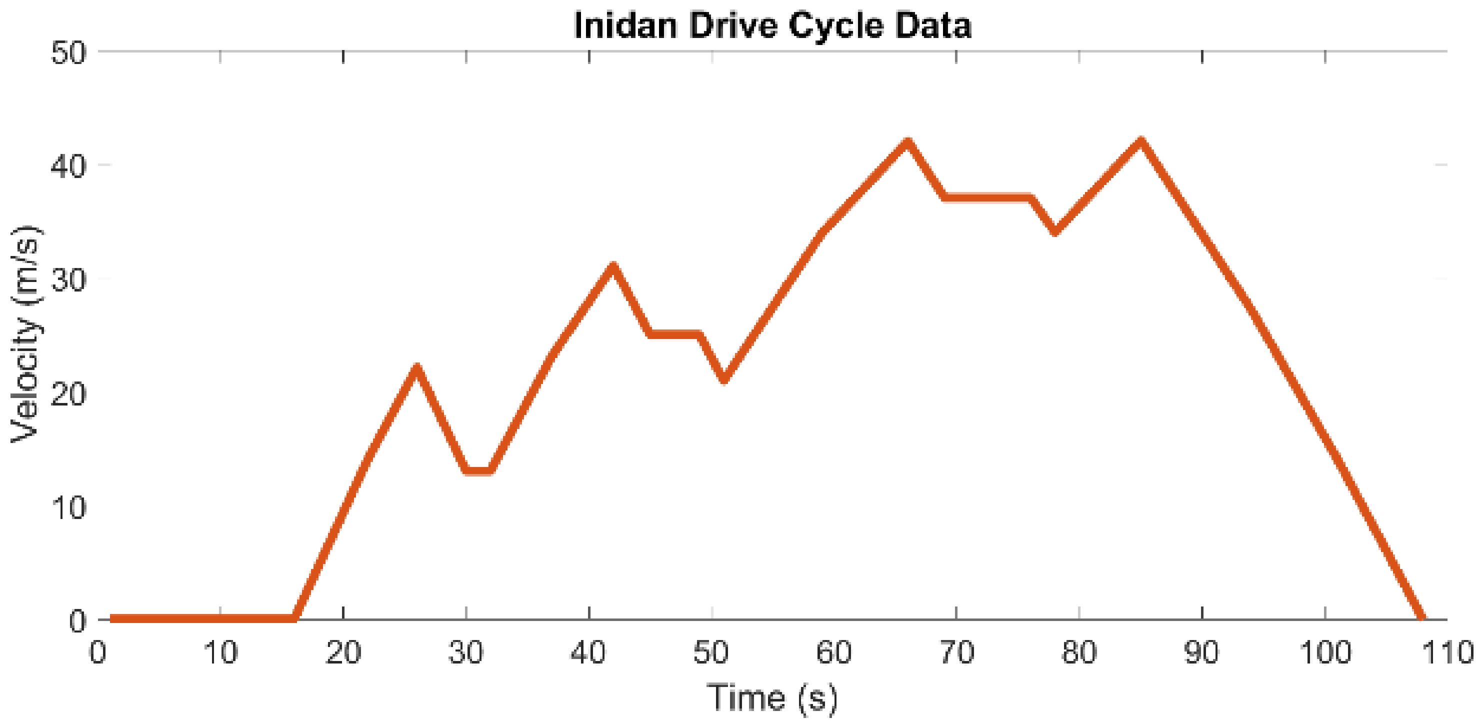
# Practice (recap)

For Tesla model 3 extended range vehicle, energy stored in battery pack is 82 kWh. Ignoring current and temperature dependance of SOC, find out the followings from the charging current profiles,

- average charging power for each stage
- charging time of each stage
- compare total charging times of different chargers
- plot the charger power rating utilization with time
- calculate and compare average power rating utilizations

# Drive cycle to test and certify EV (recap)

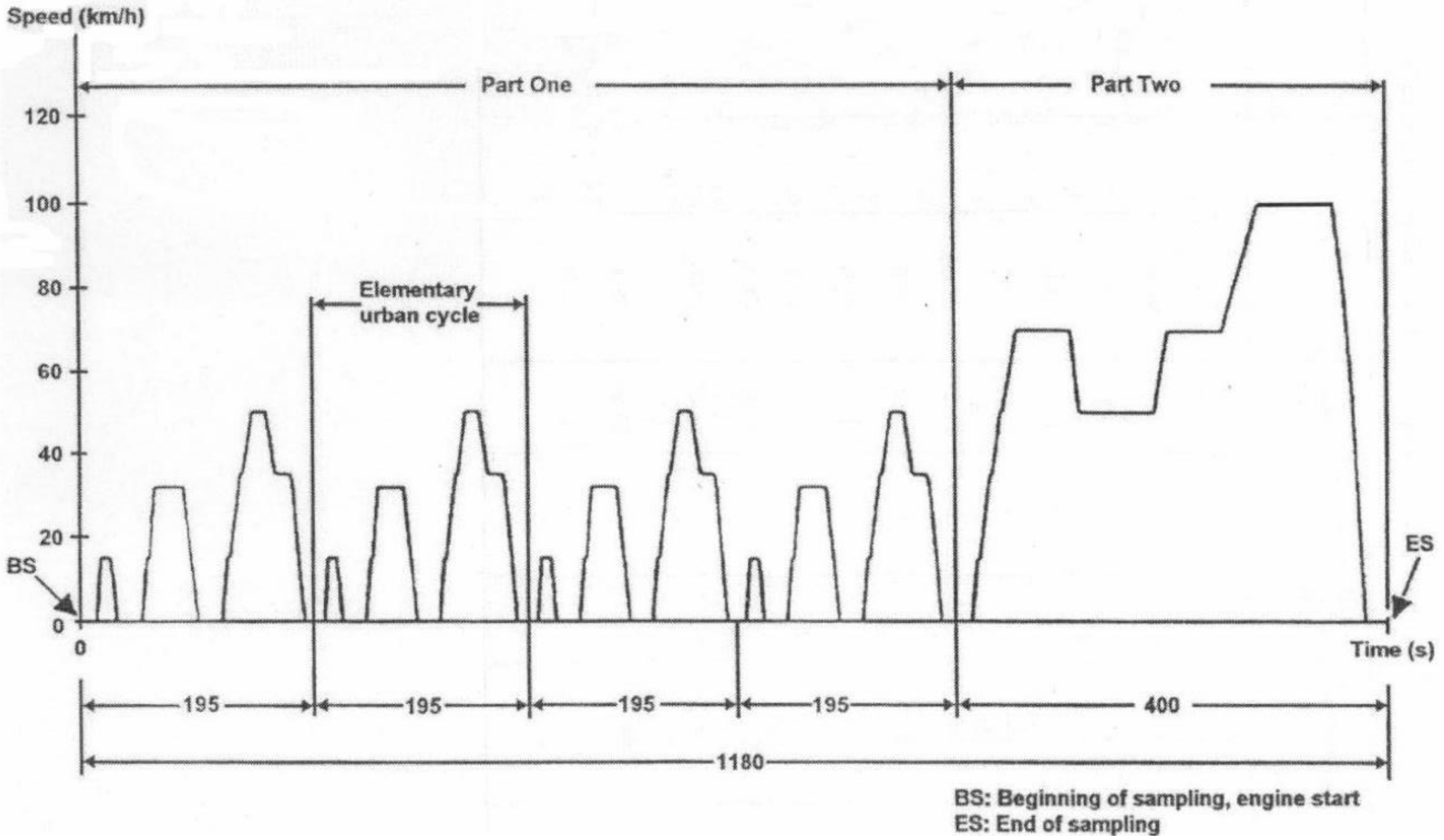
- A standard drive cycle is required to certify the range of vehicle under realistic driving scenario




Indian Driving cycle (IDC)

- Indian Driving Cycle (IDC) is developed for Indian city road condition
- Not very realistic
- Average velocity is too high

# Modified IDC (recap)




- Developed by ARAI to capture more realistic driving pattern
- Two parts
- **Part one:** Urban Driving Cycle (UDC): is for slow city driving
- **Part two:** Extra-Urban Driving Cycle (EUDC): is highway and suburban driving

# Practice (recap)

A vehicle has following parameter values:

m=692kg, $C_D$ = 0.2, $A_F$ = 2m$^2$, $f_0$ = 0.009,

$f_s$ = 1.75*10$^{-6}$ s$^2$/m$^2$, ρ = 1.18 kg/m$^3$, g = 9.81 m/s$^2$

- Find the required battery capacity (in kWh) to get a range of 100 km under IDC.
- What is the time needed to travel this distance

- Vehicle dynamic equations
  - $m\dfrac{dV}{dt} = F_{TR} - F_r - F_g - F_w$
  - Required tractive power:

$$F_{TR} = m\frac{dV}{dt} + F_r + F_g + F_w$$

$$F_r = mg\cos\alpha\,(f_0 + f_s V^2)$$

$$F_g = mg\ \sin\alpha$$

$$F_W = \frac{1}{2}\rho A_f C_D (V - V_w)^2$$

  - Power delivered by vehicle engine = $F_{TR}V$

# Factor affecting EV range

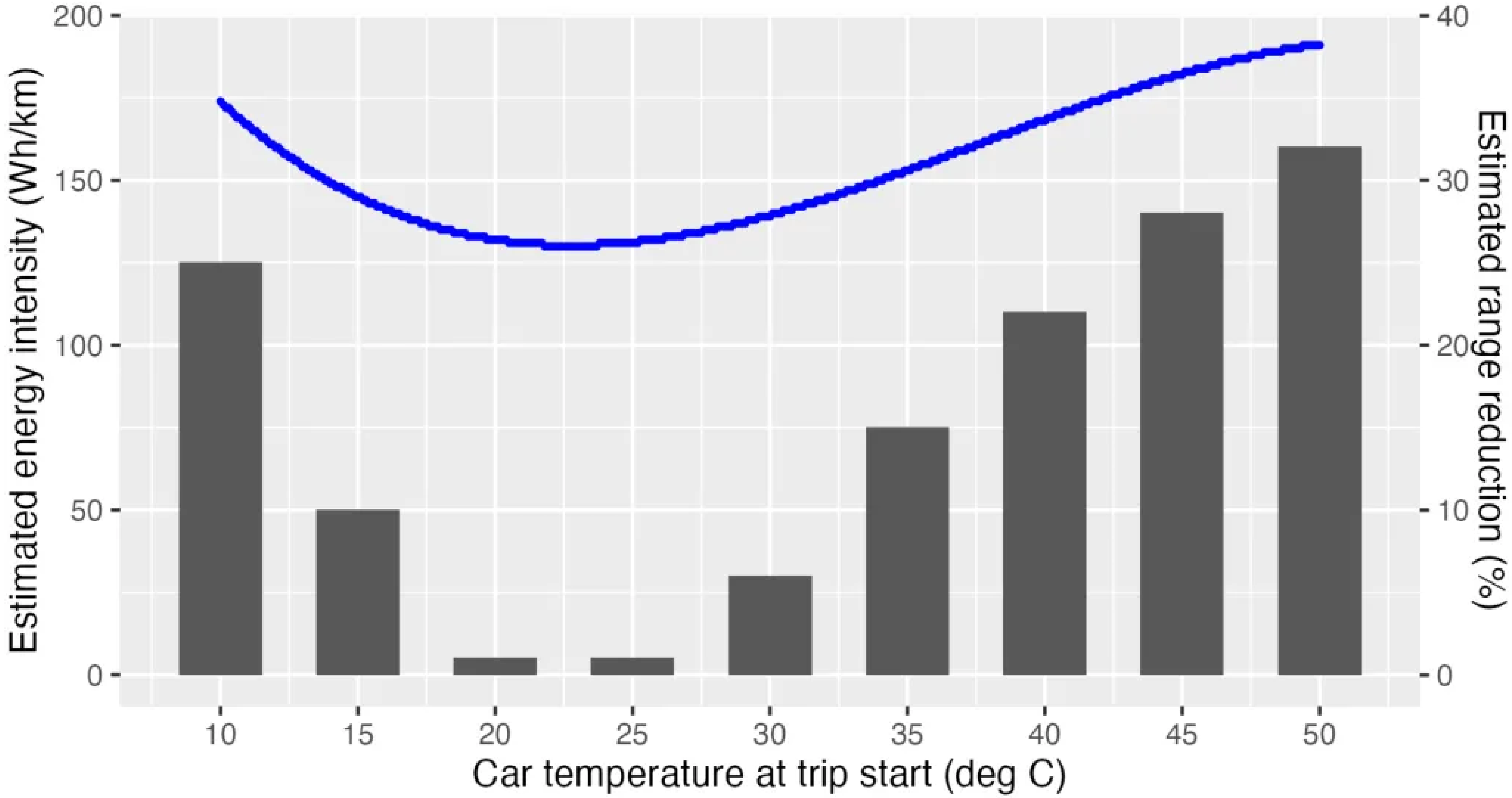
- Difficult terrains
- Adverse weather
- Power converter efficiency
- Auxiliary loads

# Power consumption by auxiliary load

| Vehicle Model | Vehicle On-road (MPG) | Vehicle On-road (Gal/mi) | Aux. Load (Gal/mi) | Aux Load % of Total Fuel Consumption |
|---|---|---|---|---|
| 2012 Honda Civic CNG | 36.3 [8] | .0275 | .00196 | 7.5% |
| 2014 Mazda 3 i-ELOOP | 31.7 [9] | .0315 | .00307 | 10.2% |
| 2013 VW Jetta TDI | 35.5 [10] | .0282 | .00484 | 18.1% |
| 2014 Chevy Cruze Diesel | 35.6 [11] | .0281 | .00320 | 12.0% |

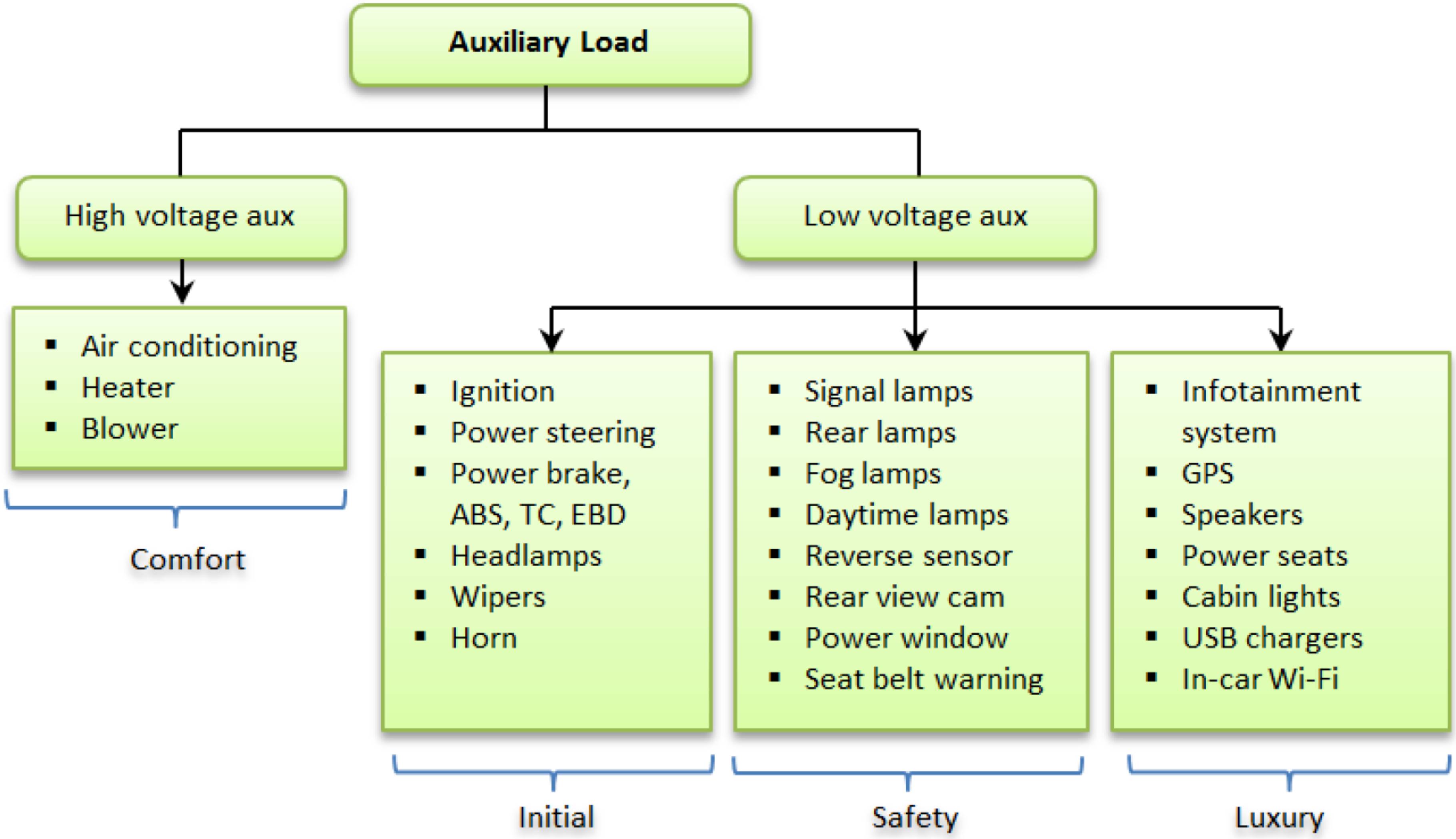
| Vehicle Model | Average Auxiliary Load (W) |
|---|---|
| 2013 VW Jetta TDI | 639.7 |
| 2014 Chevy Cruze Diesel | 561.2 |
| 2012 Honda Civic CNG | 309.8 |
| 2014 Mazda 3 i-ELOOP | 425.0 |

# Range reduction of EV due to auxiliary load

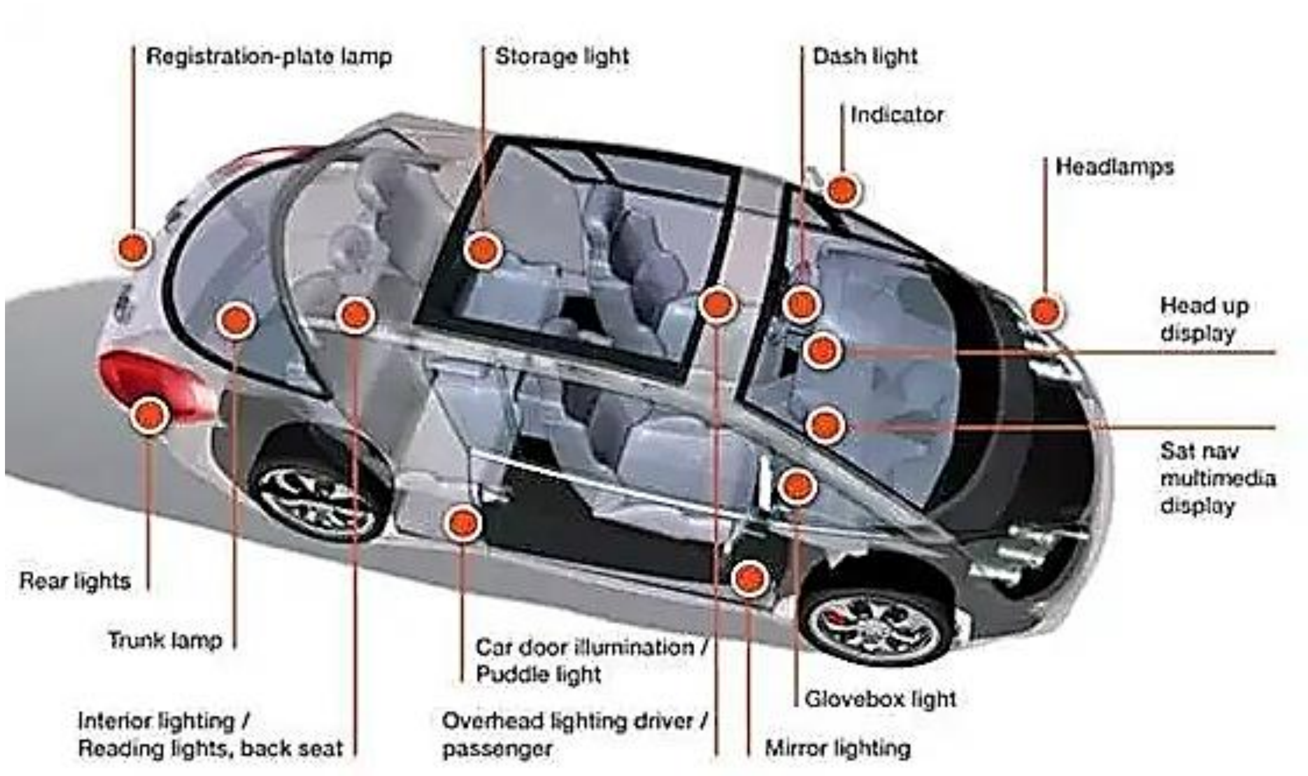



Modelled using data from Kuwait Institute For Scientific Research (KISR)

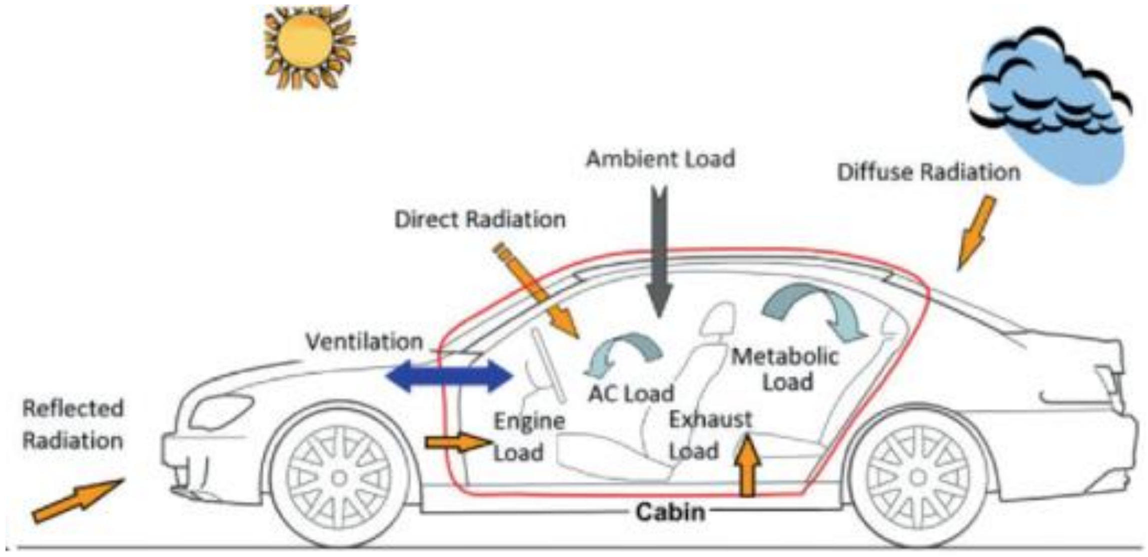
# Auxiliary loads of a car

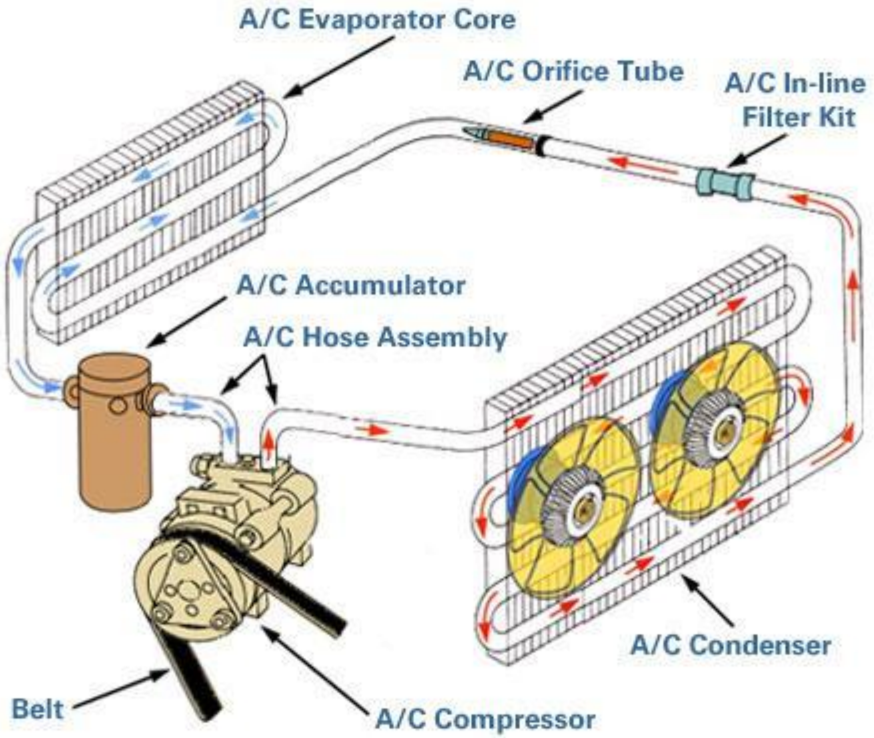


# Lighting load

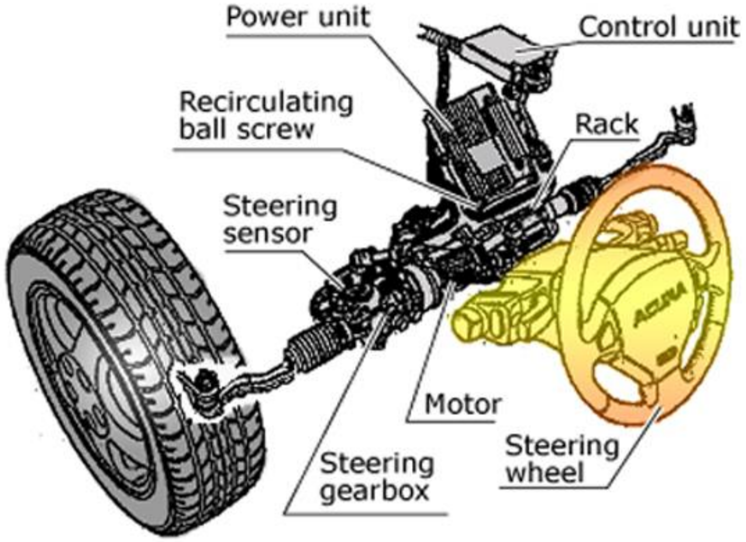


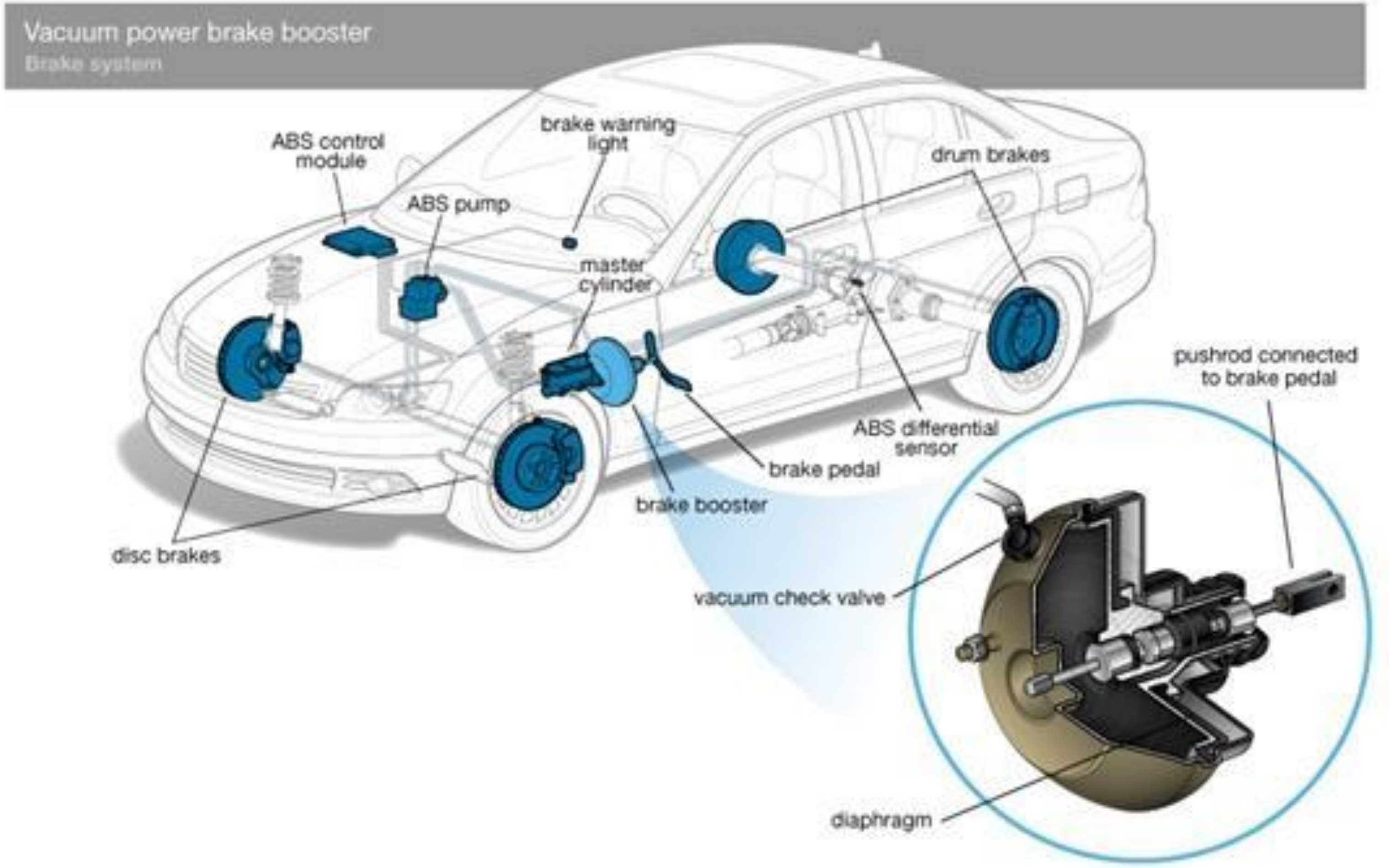
# Air-conditioning loads



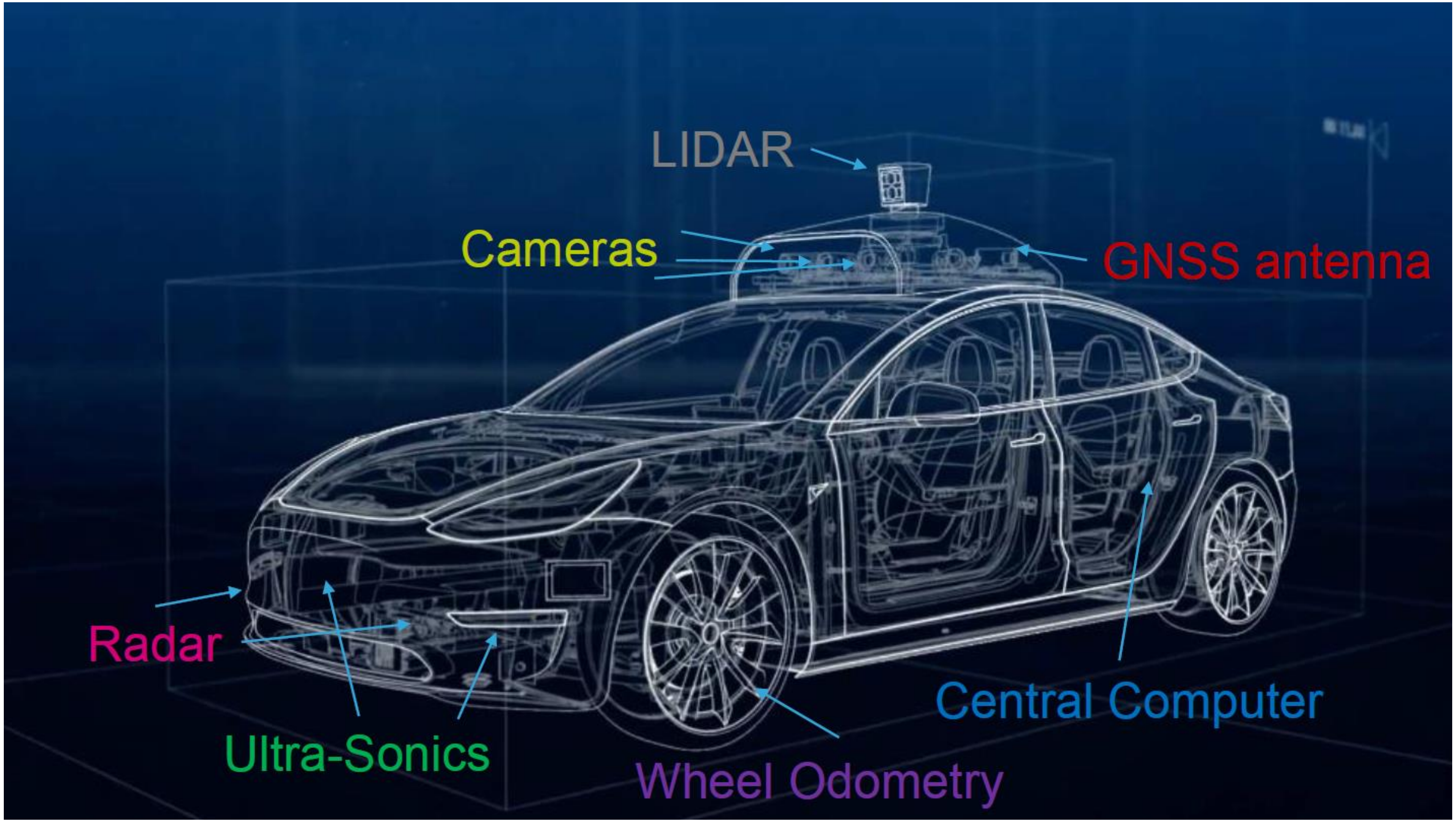
# Power steering



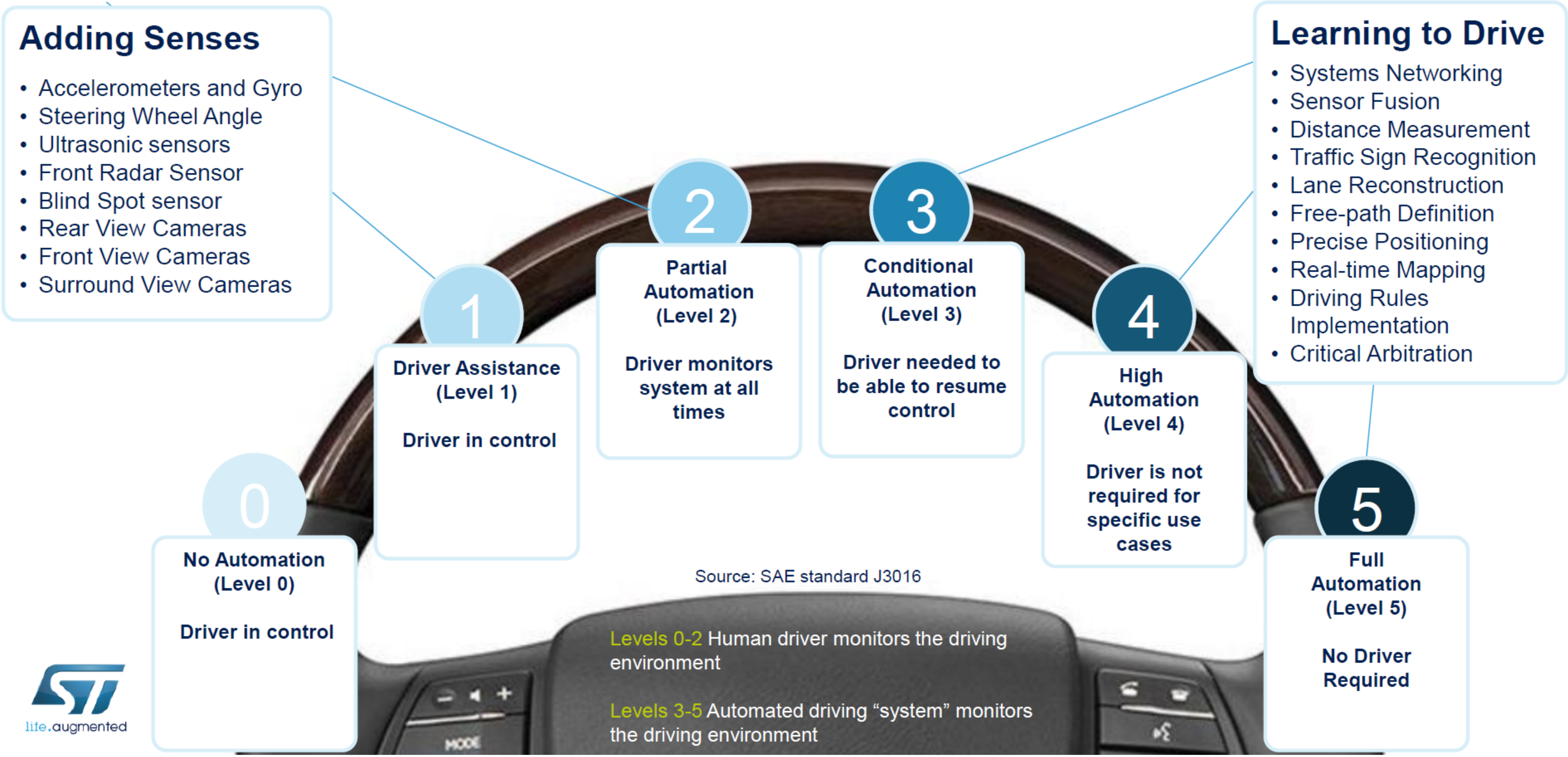



# Infotainment system

# Sensor loads



# Automation



Adding Senses
• Accelerometers and Gyro
• Steering Wheel Angle
• Ultrasonic sensors
• Front Radar Sensor
• Blind Spot sensor
• Rear View Cameras
• Front View Cameras
• Surround View Cameras
Learning to Drive
• Systems Networking
• Sensor Fusion
• Distance Measurement
• Traffic Sign Recognition
• Lane Reconstruction
• Free-path Definition
• Precise Positioning
• Real-time Mapping
• Driving Rules Implementation
• Critical Arbitration
0
No Automation (Level 0)
Driver in control
1
Driver Assistance (Level 1)
Driver in control
2
Partial Automation (Level 2)
Driver monitors system at all times
3
Conditional Automation (Level 3)
Driver needed to be able to resume control
4
High Automation (Level 4)
Driver is not required for specific use cases
5
Full Automation (Level 5)
No Driver Required
Source: SAE standard J3016
Levels 0-2 Human driver monitors the driving environment
Levels 3-5 Automated driving "system" monitors the driving environment
MODE
life.augmented

# Sensors for automated driving

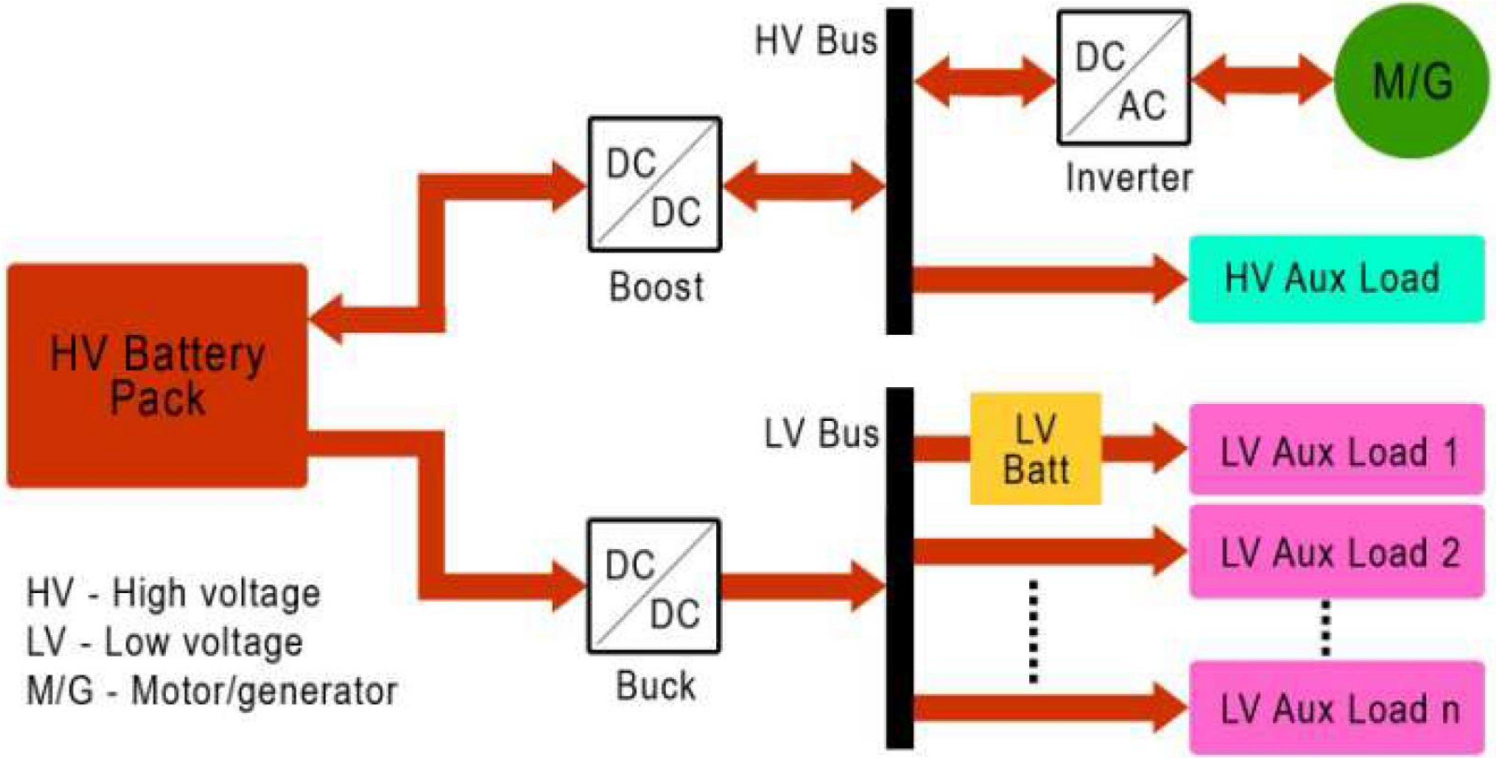
**No sensor type works well for all tasks and in all conditions, so sensor fusion will be necessary to provide redundancy for autonomous functions**

Most likely used fusion solution in future | Good | Fair | Poor

| | Camera | Radar | LiDAR | Ultrasonic | LiDAR+Radar+ Camera |
|---|---|---|---|---|---|
| Object detection | Fair | Good | Good | Good | Good |
| Object classification | Good | Poor | Fair | Poor | Good |
| Distance estimation | Fair | Good | Good | Good | Good |
| Object edge precision | Good | Poor | Good | Good | Good |
| Lane tracking | Good | Poor | Poor | Poor | Good |
| Range of visibility | Fair | Good | Fair | Poor | Good |
| Functionality in bad weather | Poor | Good | Fair | Good | Good |
| Functionality in poor lighting | Fair | Good | Good | Good | Good |

# Auxiliary Power Module (APM)

- APM: power converter required to supply auxiliary load



# Example Requirements for APM (buck)

- $V_{in}$: 220~450VDC (nominal power);
- $V_o$: 10~16VDC (nominal current);
- $P_o$: 400W (nominal power);
  >2kW (maximum power).
- T: 70~85°C (nominal power);
- Isolation is required due to the safety concern

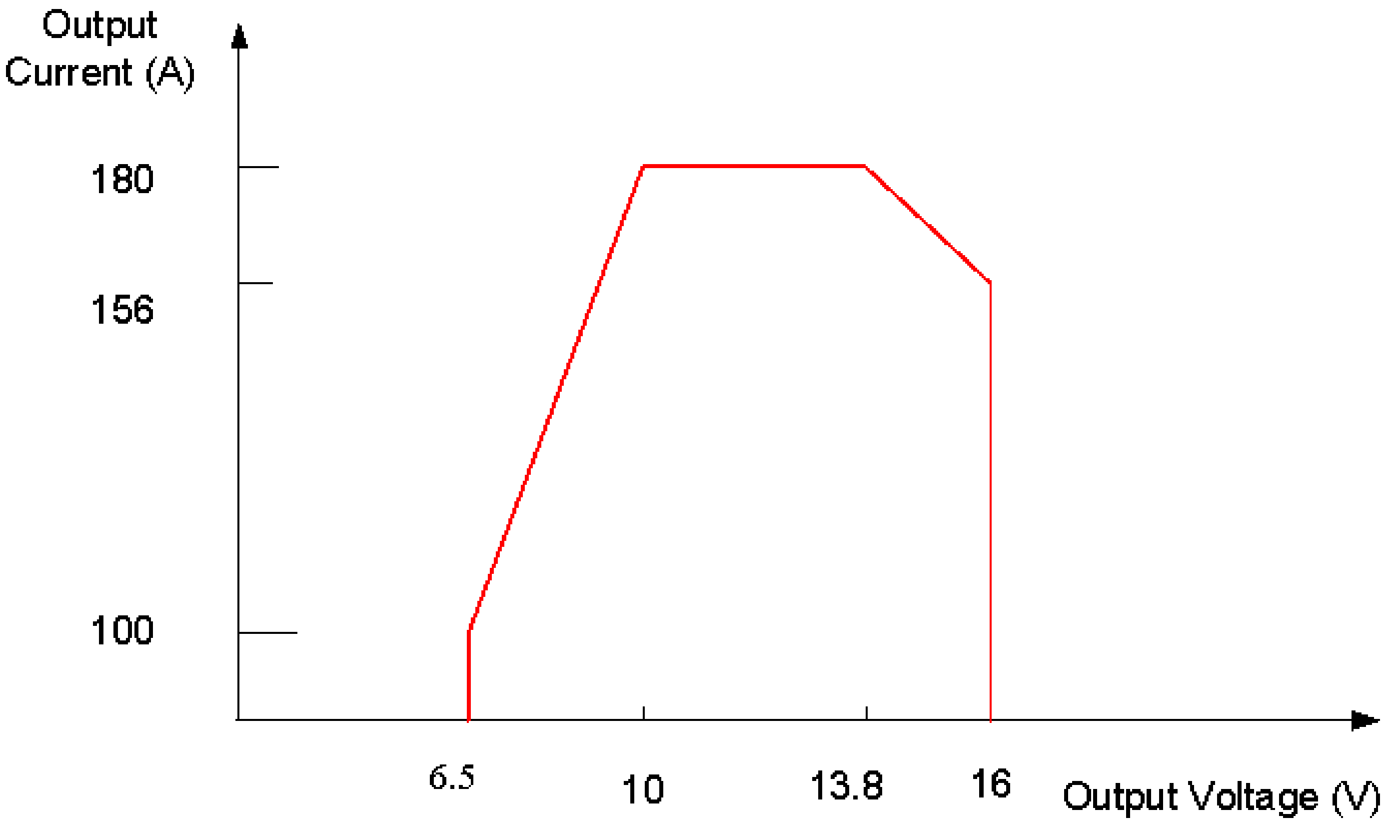
Question:

- What is the range of voltage gain?

Challenges:

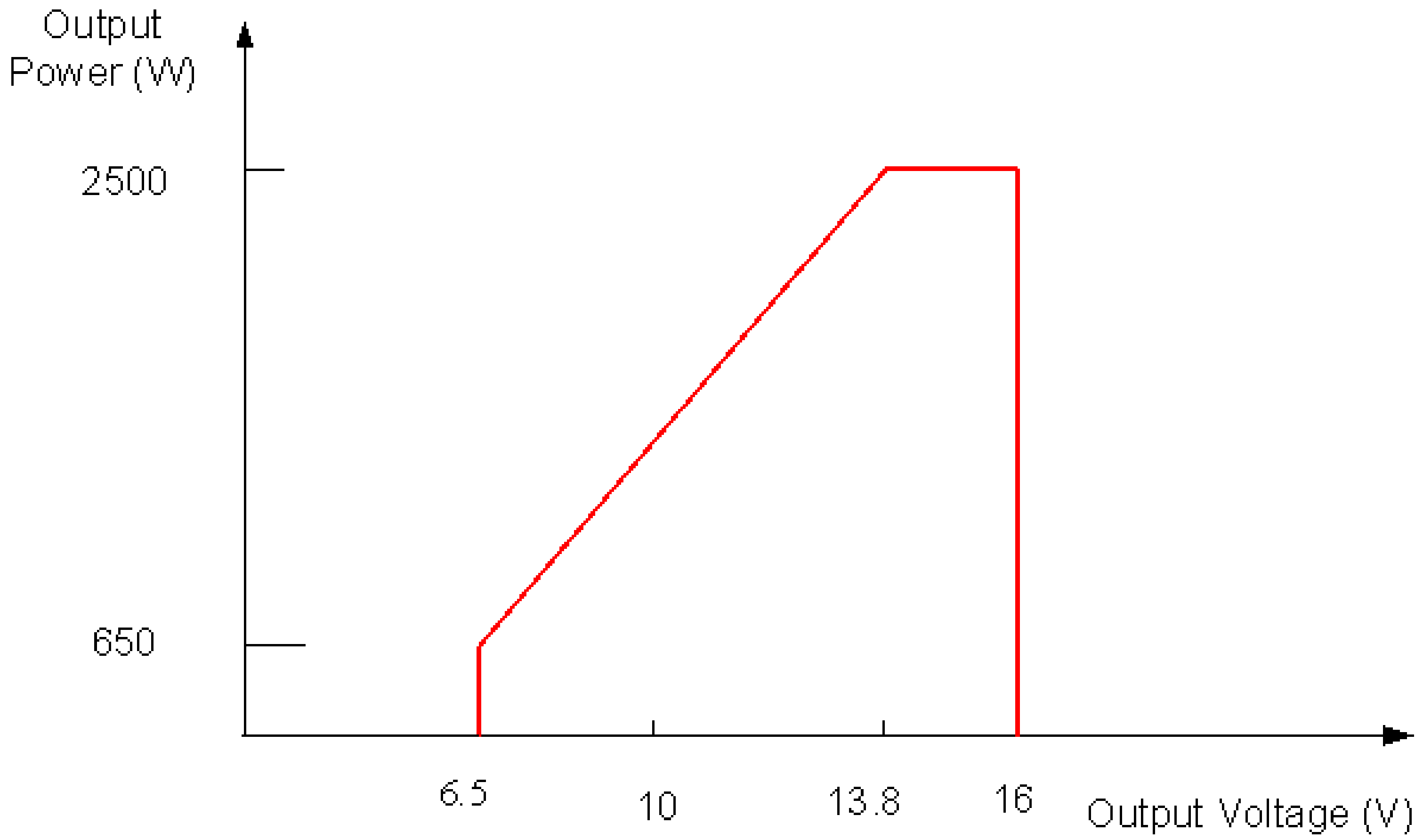
- Wide variation in input and output voltage
- Large voltage gain

# APM buck example 1



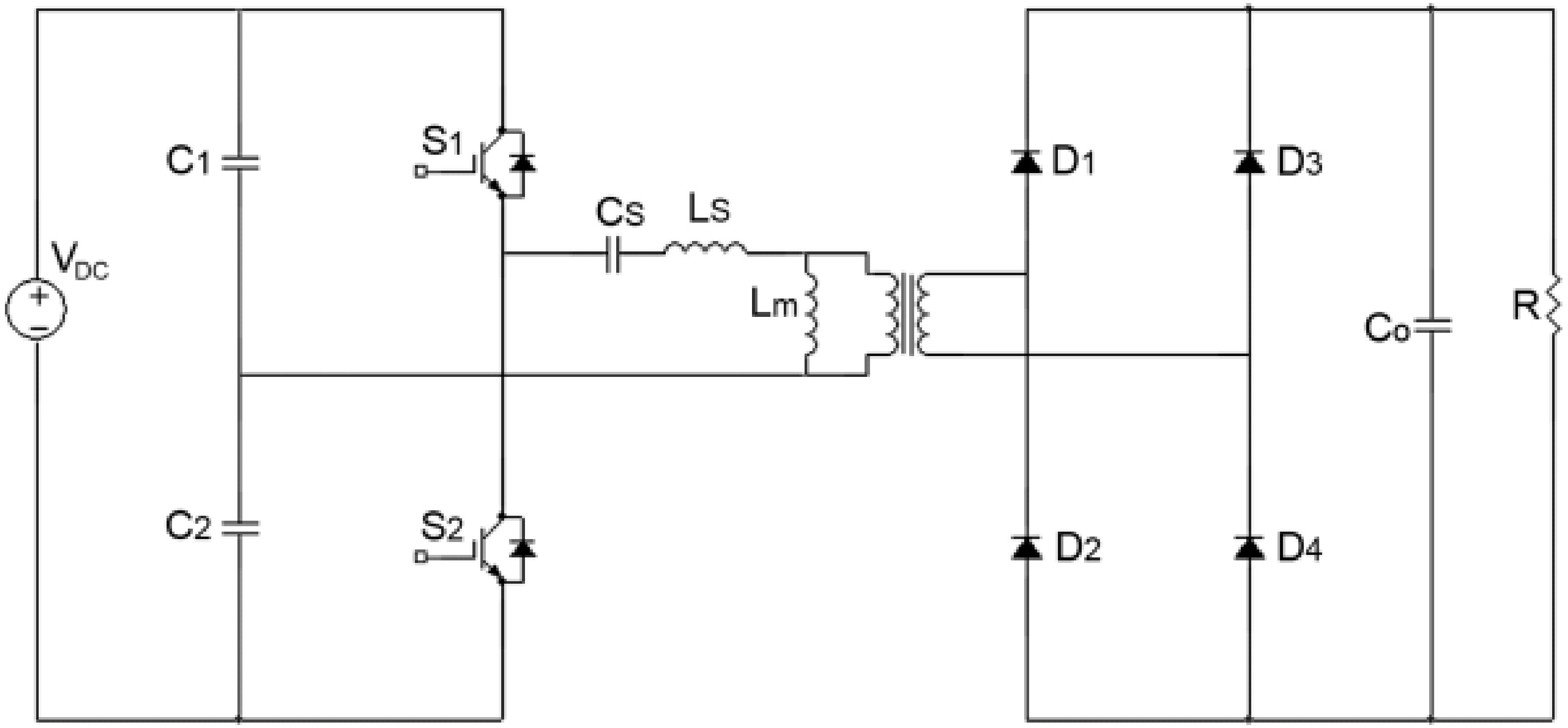

Buck converter output current vs output voltage

# APM buck example 2




Buck converter output power vs output voltage requirement

# Solution-1




220~450VDC

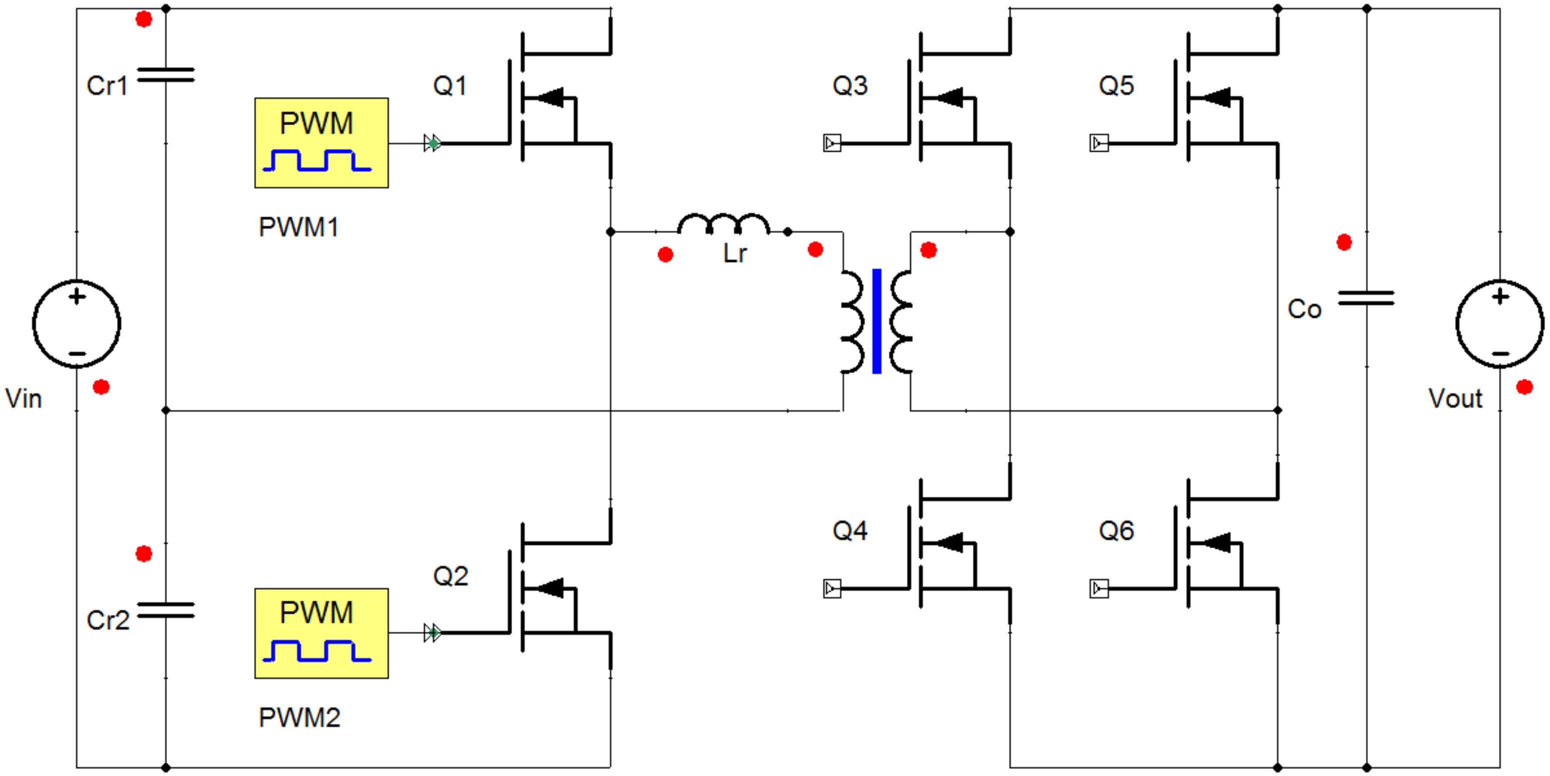
6.5~16VDC

**$C_s$=0.1µF, $L_s$=5.4 µH, $L_m$=16.5 µH**

Challenges?

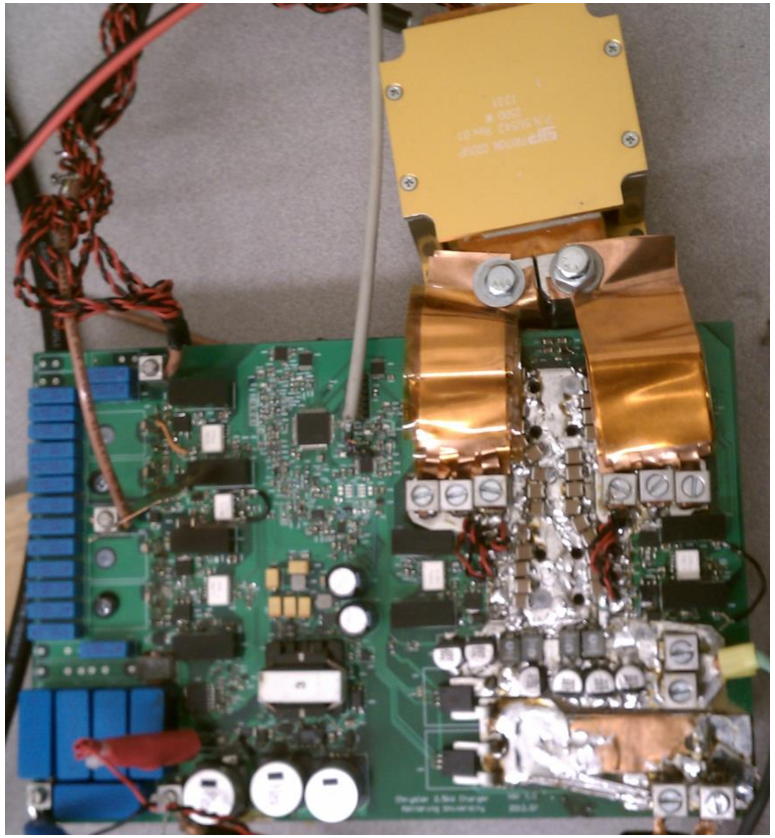
- large secondary current
- High loss in diodes

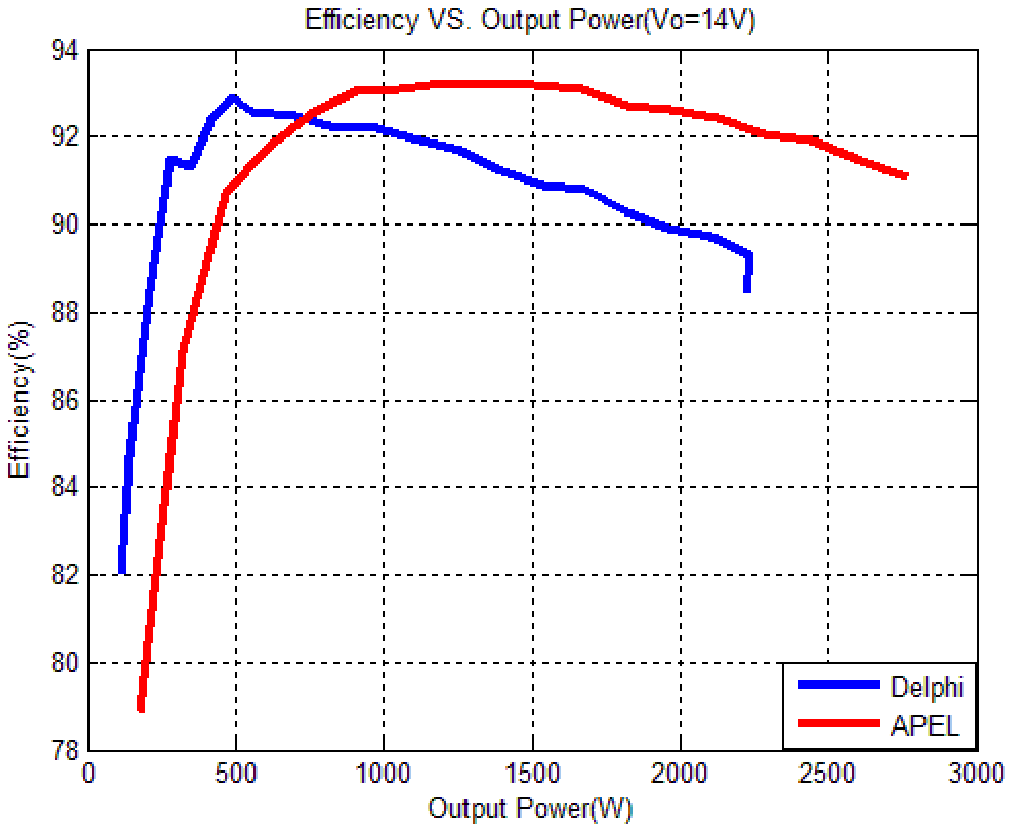
# Solution-2




Solution: HB at the primary and FB at the secondary.

# Efficiency





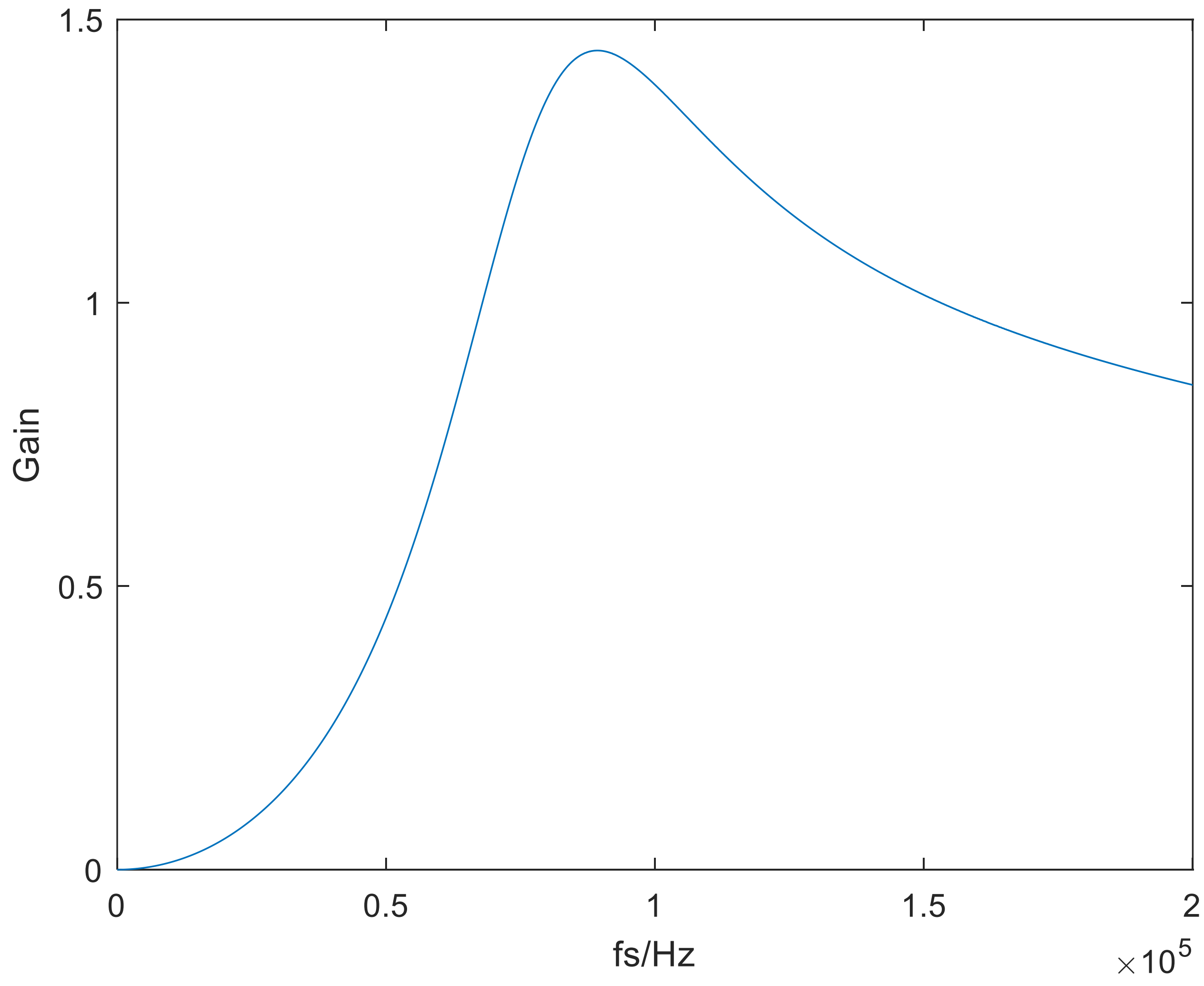
Efficiency VS. Output Power(Vo=14V)
94
92
90
88
86
84
82
80
78
Efficiency(%)
0
500
1000
1500
2000
2500
3000
Output Power(W)
Delphi
APEL

# LLC resonance converter gain

Challenges:

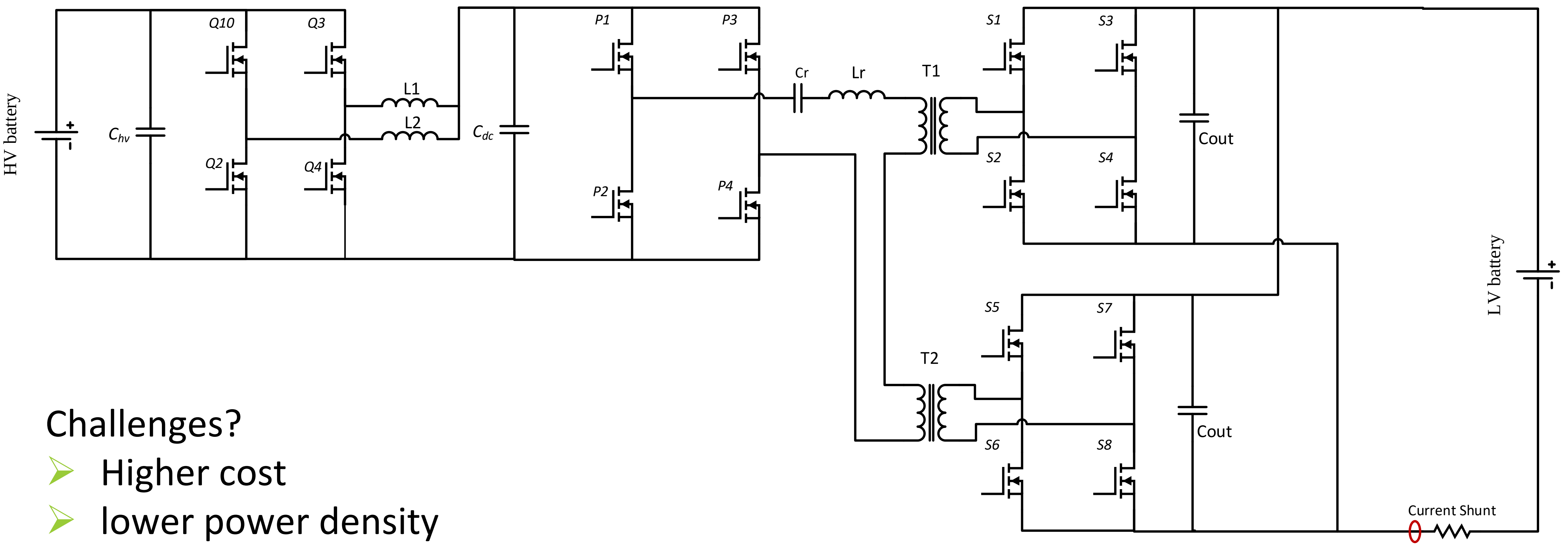
- Large variation in switching frequency

- Difficult to achieve wide range of voltage gain (why?)



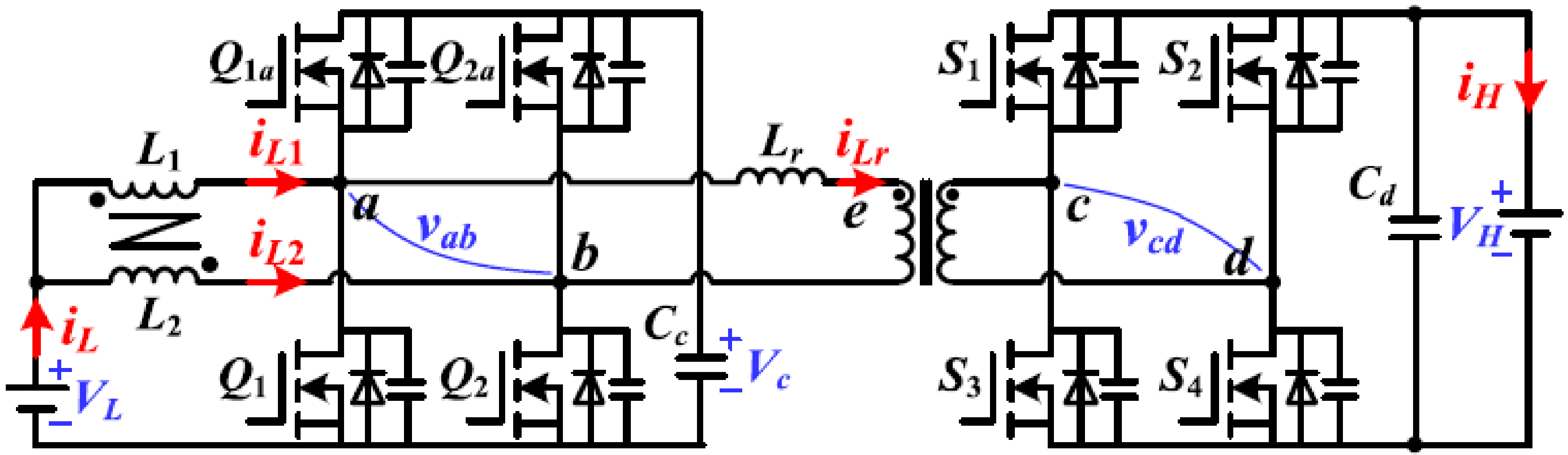
# Solution-3

**Two-stage Design:   Buck + DCX**



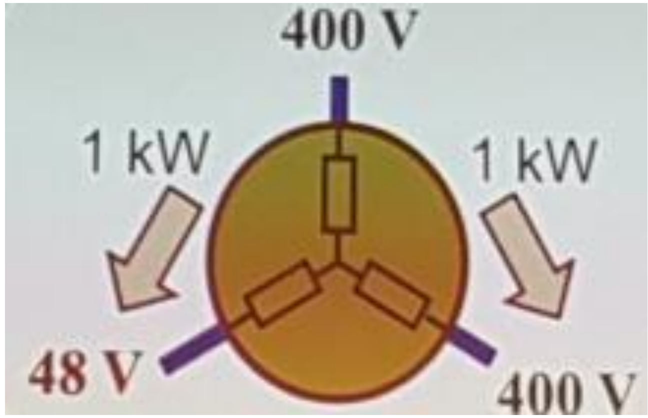

Challenges?
- Higher cost
- lower power density

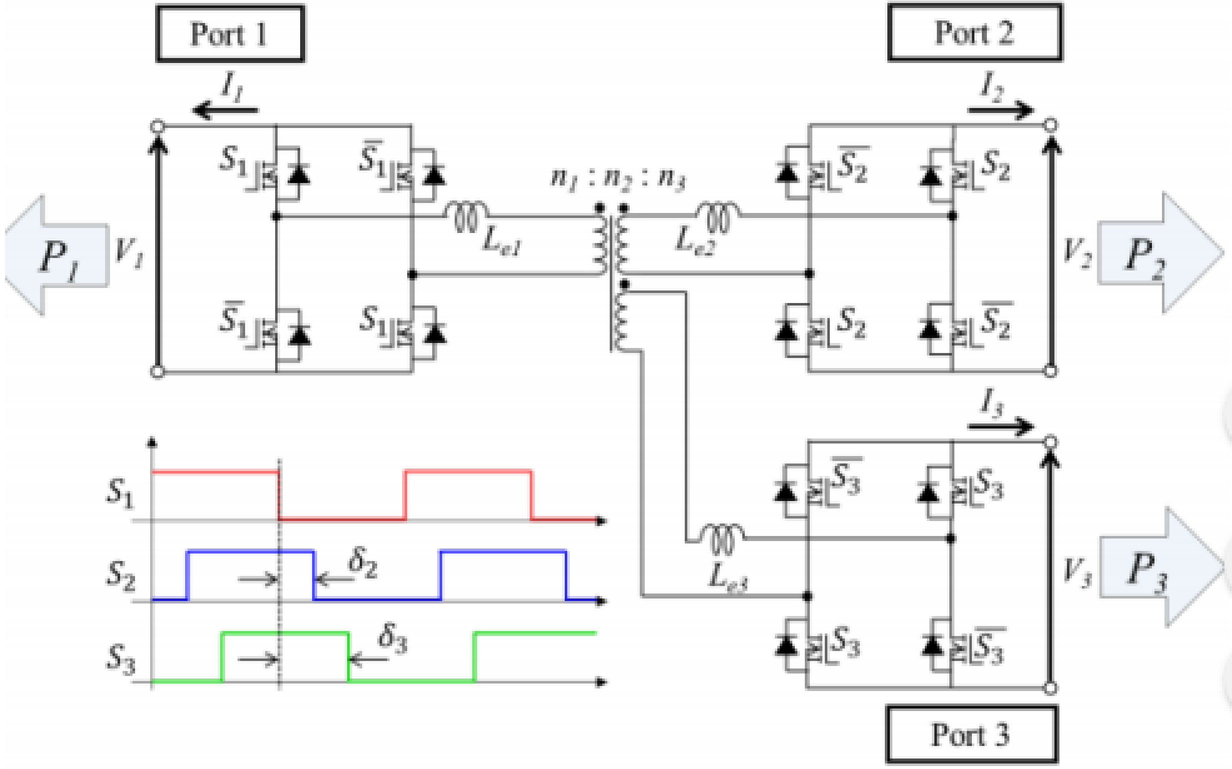
# Solution-4




- Inductor size might be large;

# Solution-5: APM + Charger




**Note: APM must work even when car is parked for charging!**

# The end!

# End-term exam

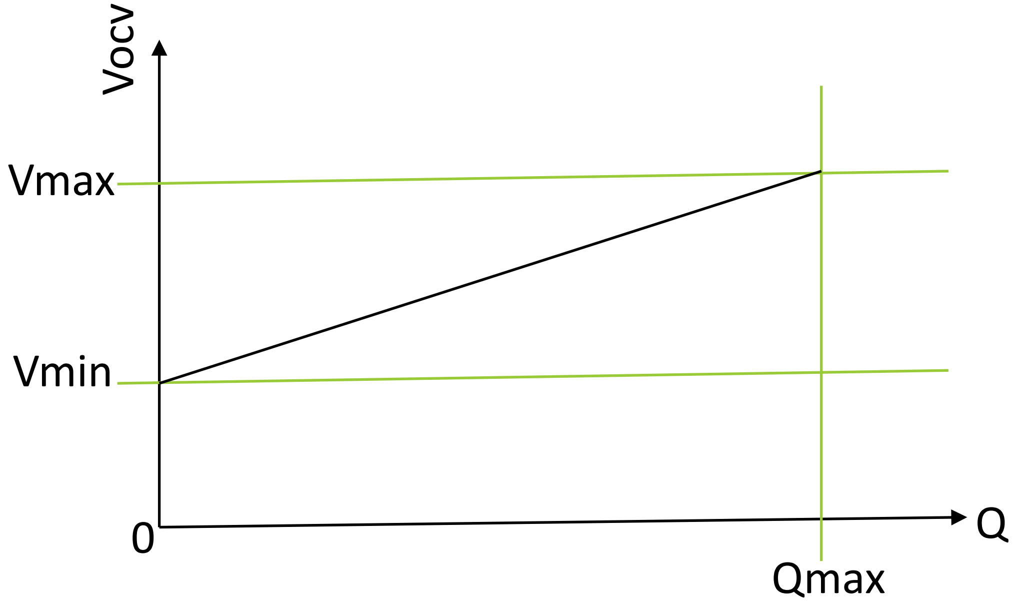
- 3 hr exam, closed book
- Date: April 25th, 2025, 9am-12pm, F-244 (please verify yourself)
- Syllabus: entire course content
- 100 points (contributes to 50% of grading)

# Assignment

## Part A:

Develop a Simulink model for a battery pack with the following parameters:

- Charge capacity, Qmax = 100 Ah
- Maximum OCV, Vmax=420V
- Minimum OCV, Vmin=280V
- Internal resistance, Rs=1mΩ
- Initial charge in battery pack = Qini (which can be up to Qmax)
- OCV of the pack follows the relation in the figure on the right




Problem: Simulate and plot the terminal voltage Vt vs. time for constant current discharge with 1C and 2C rate from fully charged condition. What are the time for complete discharge and total charge delivered to load in each case?

# Assignment

Part B:

Simulate the battery pack model and vehicle model together.

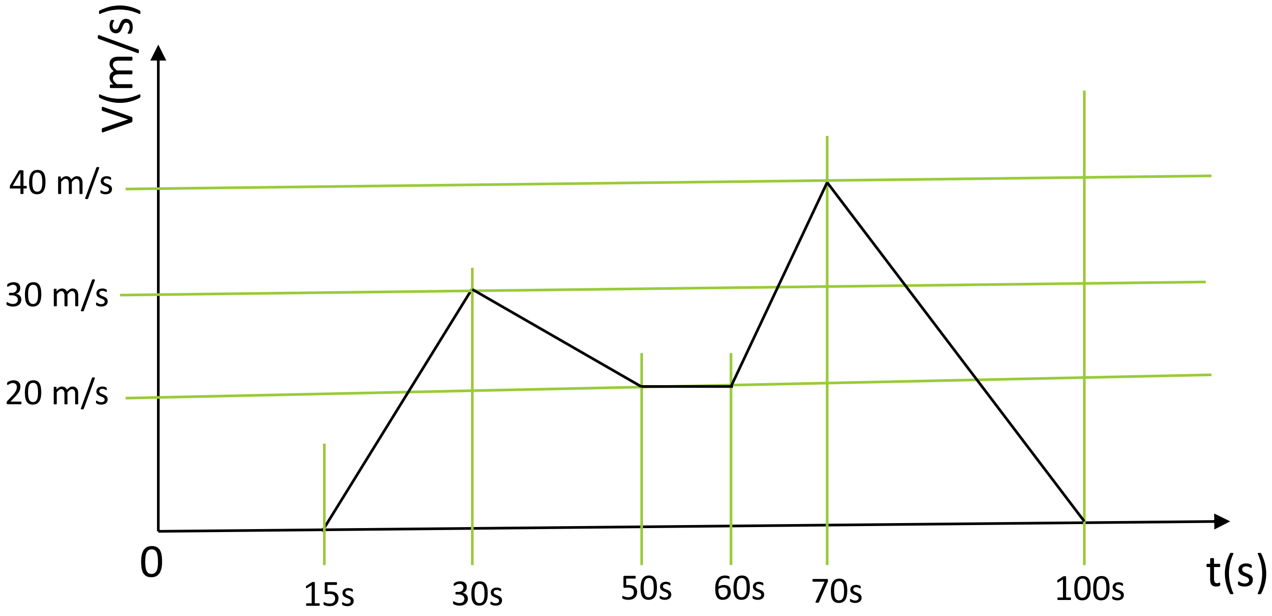
- Use same battery parameters as part A.
- Vehicle parameters:

  $m = 692 kg$, $C_D = 0.2$, $A_F = 2 m^2$, $f_0 = 0.009$,

  $f_s = 1.75*10\text{-}6\ s^2/m^2$, $\rho = 1.18\ kg/m^3$, $g = 9.81\ m/s^2$,

  wind speed $V_w=0$, $\alpha=0$

- Simulate required power for EV when following the drive cycle in the figure on the right (drive cycle repeat every 100s).
- Simulate the battery current and voltage using controlled current source as vehicle load.
- Find the range of the vehicle
- Plot battery current, voltage, power, and vehicle velocity separately in same scope (4 channel scope)



# Assignment

## Report submission

- Submit a ppt or a pdf file with the following
  - Screenshots of simulation models
  - Screenshots of results
  - Your findings

- Submission method
  - Online through MS teams
  - Link will be shared soon

- Submission deadline
  - May 4th, 11:59pm
  - Hard deadline (no late submission acceptable)

- Assignment grading
  - grading based on efforts (try to attempt all the parts)
  - 20% contribution towards final grading

Thank you!