# EXPECTED PERFORMANCE OF A TRACTION DRIVE

- The major tasks that a vehicle must complete within a reasonable time frame are:
  - Traveling on level roads
  - Going uphill and down hill
  - Stopping at red lights
  - Accelerating on the highways or for overtaking

- These aspects are affected by the torque-speed relationship of the engine or motor.

- A vehicle's ability to start moving, go uphill, and acceleration depends on Torque.

- How fast it moves and how long it takes to travel a given distance depends on Speed.

# EXPECTED PERFORMANCE OF A TRACTION DRIVE

- The major issue faced by designers is determining the torque and speed required to meet the vehicle's intended uses.
- This is a challenging situation because torque and speed have an inverse relationship.
- Since the engine power, $P = \omega T$, for a constant power:

$$T \propto \frac{1}{\omega}$$

where, $\omega$ = speed
$T$ = torque

- In engine vehicles, these requirements are met by complex gear systems.

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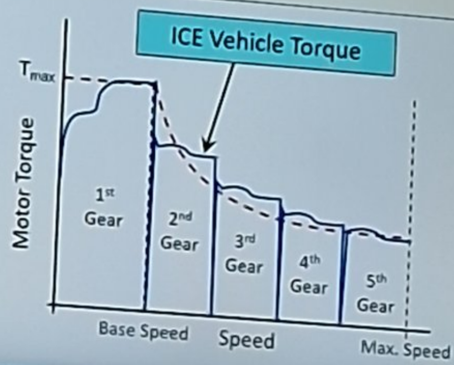
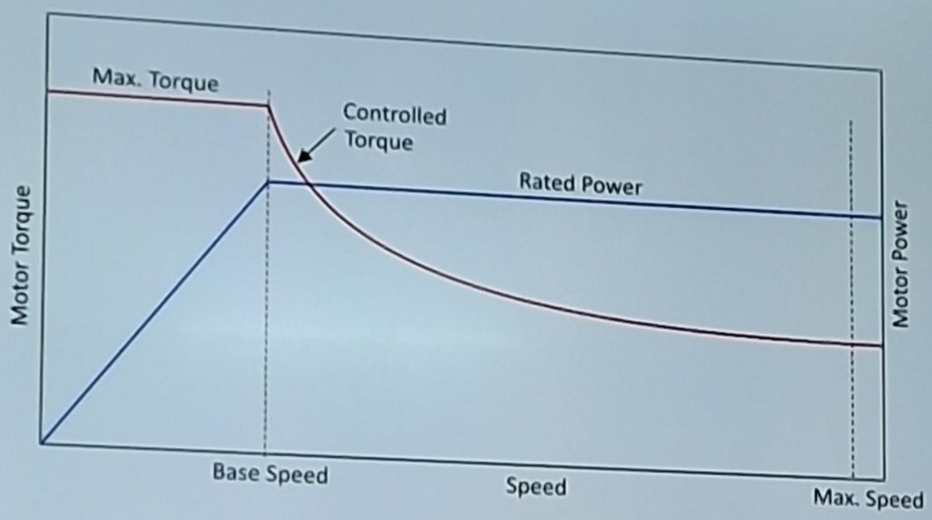


# EXPECTED PERFORMANCE OF A TRACTION DRIVE

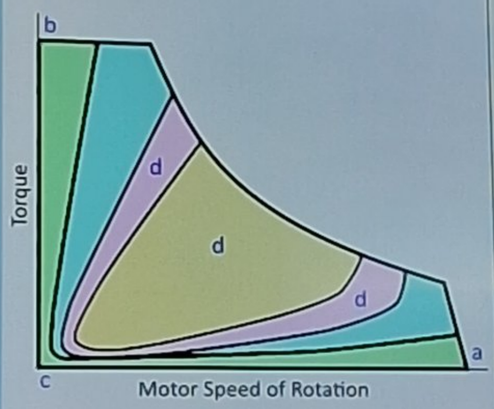
- The ideal torque-speed profile is constant power over all speed ranges.
- Vehicles need a constant torque at low speeds, but a constant power at high speeds.
- A well-controlled electric motor can easily produce such a profile.

- Advantages of Electric Motors
  - Large speed ranger of electric motors → no need for higher gears
  - High torque output at low speed → no need for lower gear
  - Launch vehicle at zero speed → no need to idle at low rpm
  - High efficiency in the wide operating range

# PERFORMANCE OF A TRACTION MOTOR



# THE ADVANTAGES OF ELECTRIC MOTORS




(a) Larger speed range of motors enables EVs to reach high speed without help of higher gears.

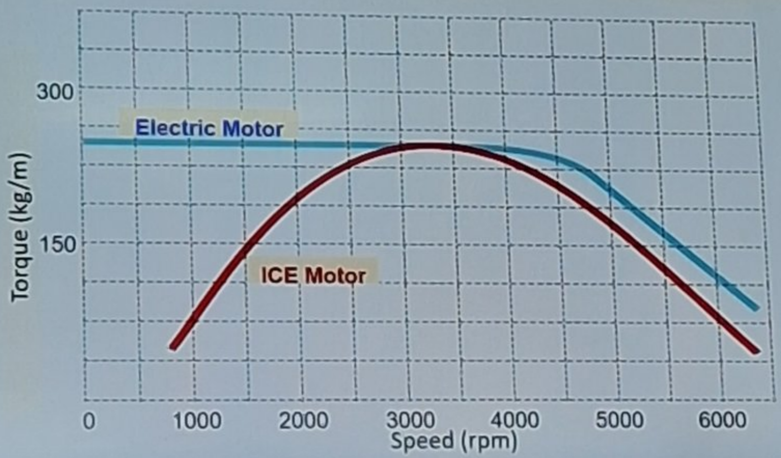
(b) Huge torque at low speeds allows EVs to accelerate quickly without using low gears to increase torque.

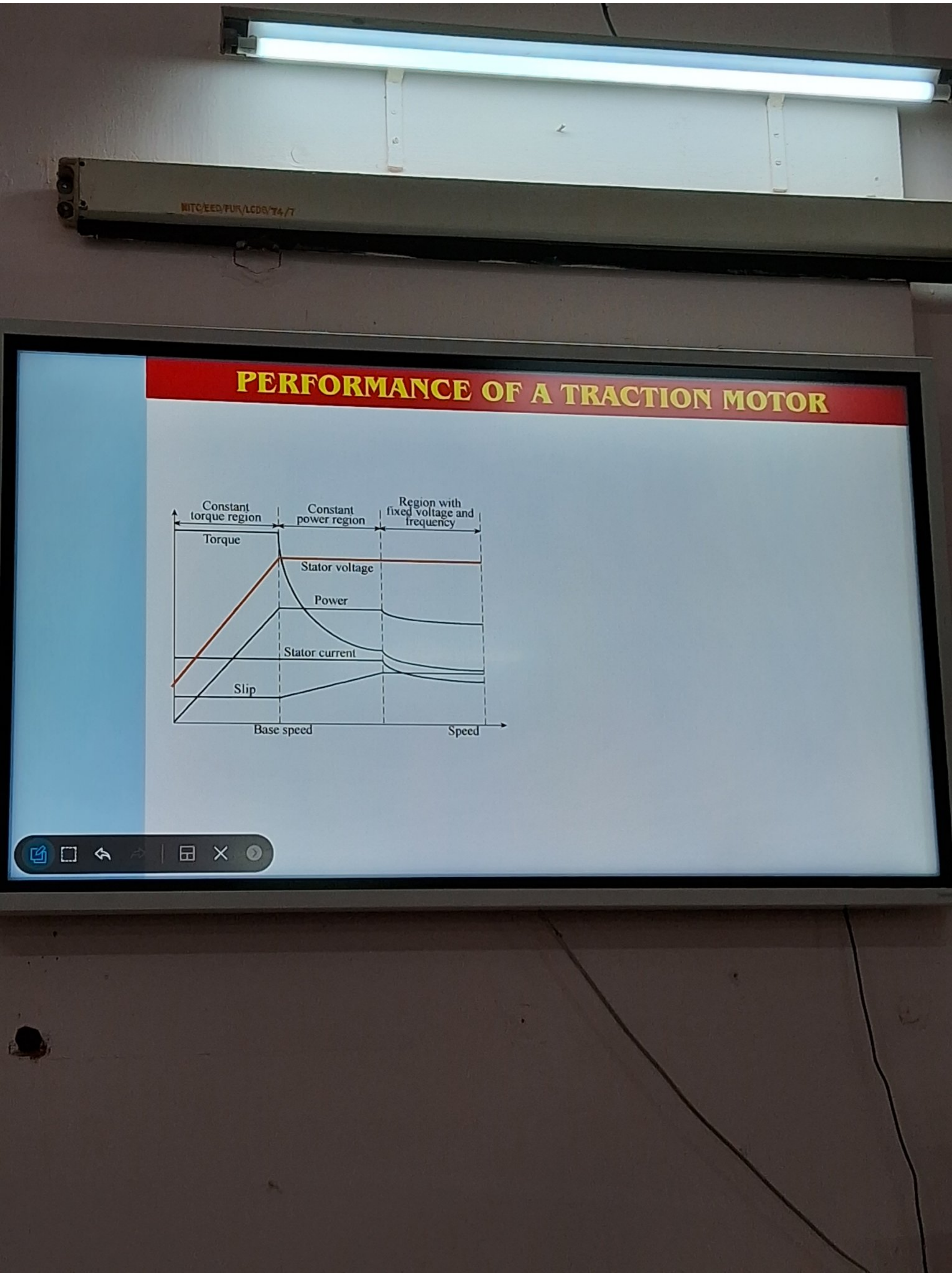
(c) Motors can start the vehicle at zero speed, while the ICE must be idle (~ 800 rpm) to start the vehicle using the clutch or torque converter.

(d) Compared to the ICE, motor efficiency is well above 85%, and the efficiency curve over the entire operating range is very flat compared to the ICE.

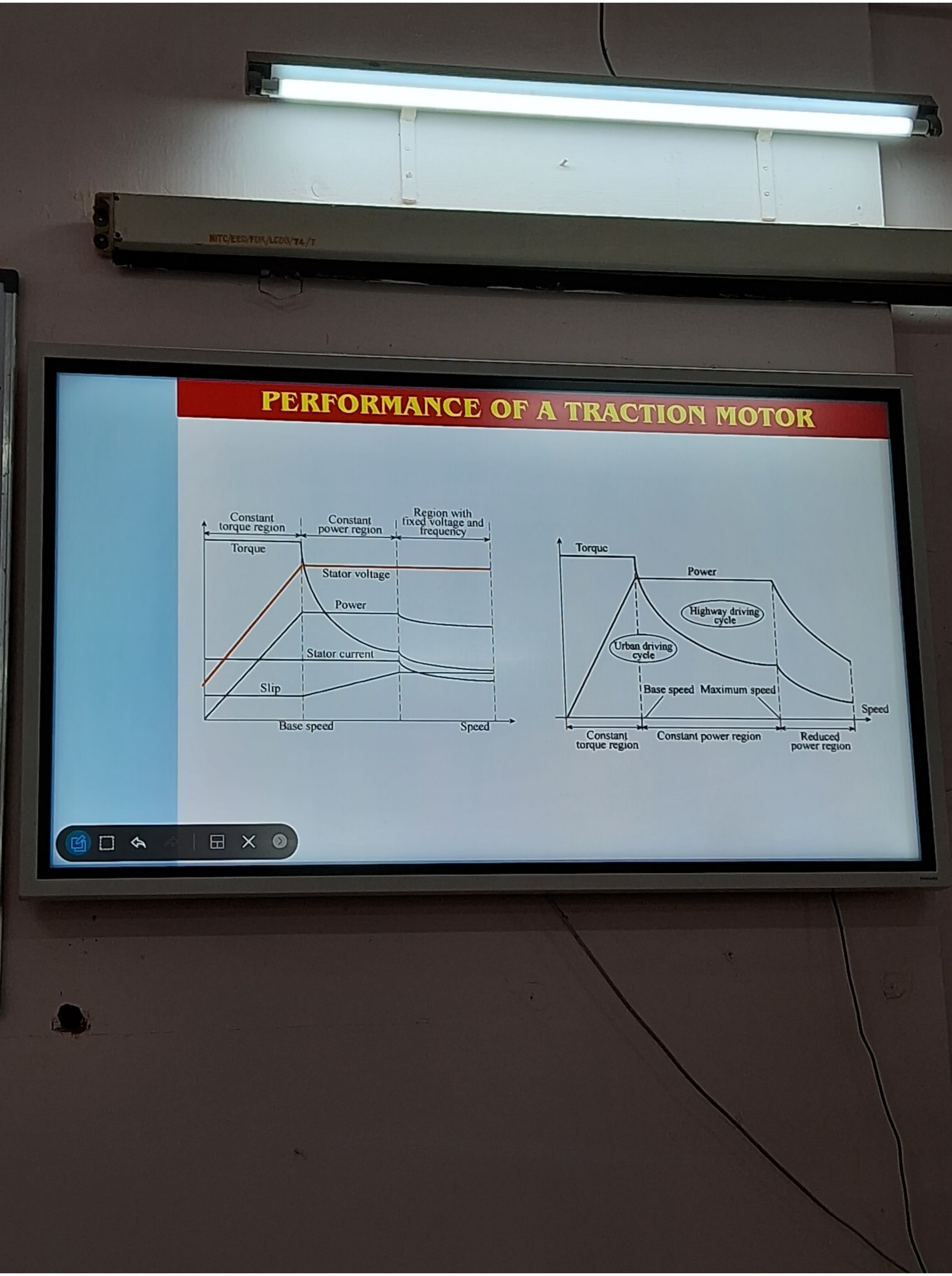
# VEHICLE TORQUE: ENGINE VS. MOTOR

- An electric motor can produce very large torque even at 0 rpm ($T = P/\omega$).
- Motor torque output remains nearly constant, up to speeds of about 5000 rpm.
- Because motors produce constant torque nearly at all speeds, EVs do not require multiple speed transmissions (i.e., gears).



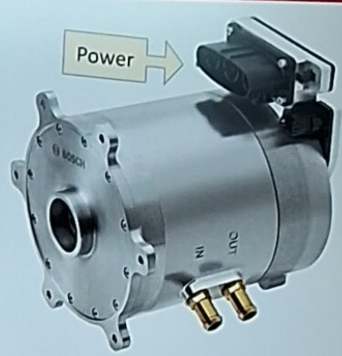


PERFORMANCE OF A TRACTION MOTOR
Constant torque region
Constant power region
Region with fixed voltage and frequency
Torque
Stator voltage
Power
Stator current
Slip
Base speed
Speed


PERFORMANCE OF A TRACTION MOTOR
Constant torque region
Constant power region
Region with fixed voltage and frequency
Torque
Stator voltage
Power
Stator current
Slip
Base speed
Speed
Torque
Power
Highway driving cycle
Urban driving cycle
Base speed
Maximum speed
Speed
Constant torque region
Constant power region
Reduced power region

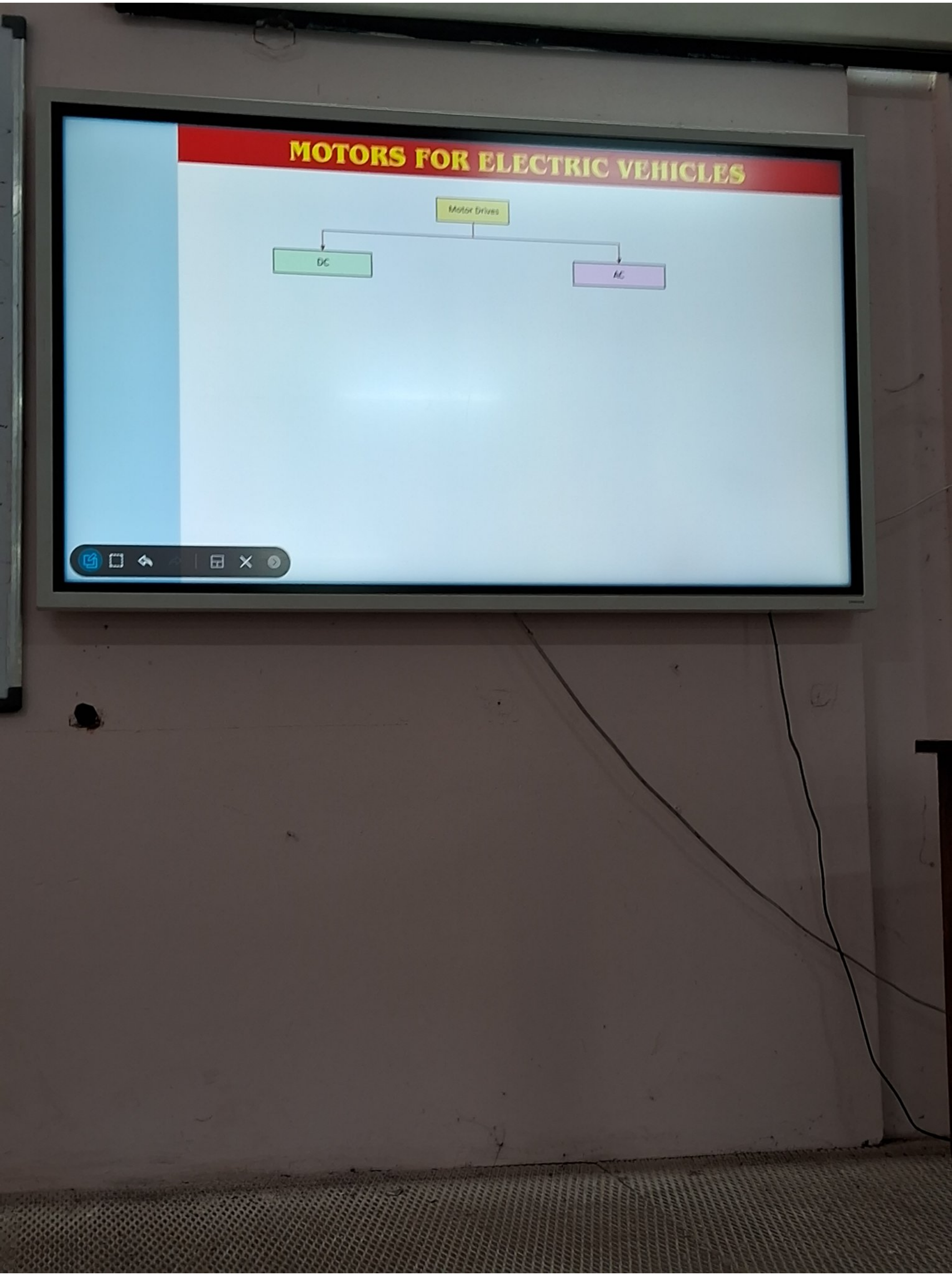
# TRACTION MOTORS IN ELECTRIC VEHICLES

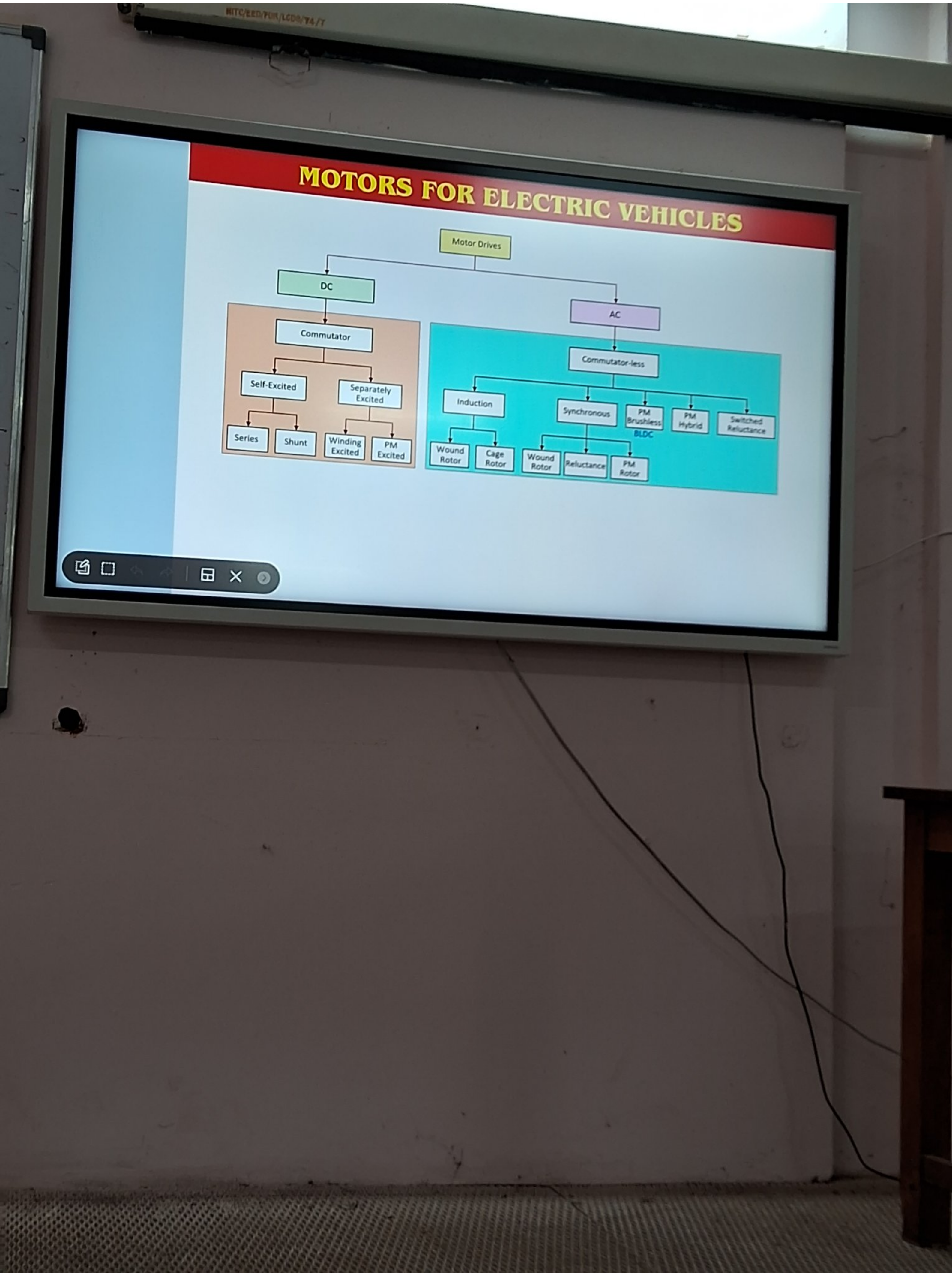
- Electric motors are more compact and efficient as compared to IC engines.
- A typical petrol engine has an efficiency in the range of 25 – 30%.
- However, electric motors typically have efficiency between 95 to 98%.

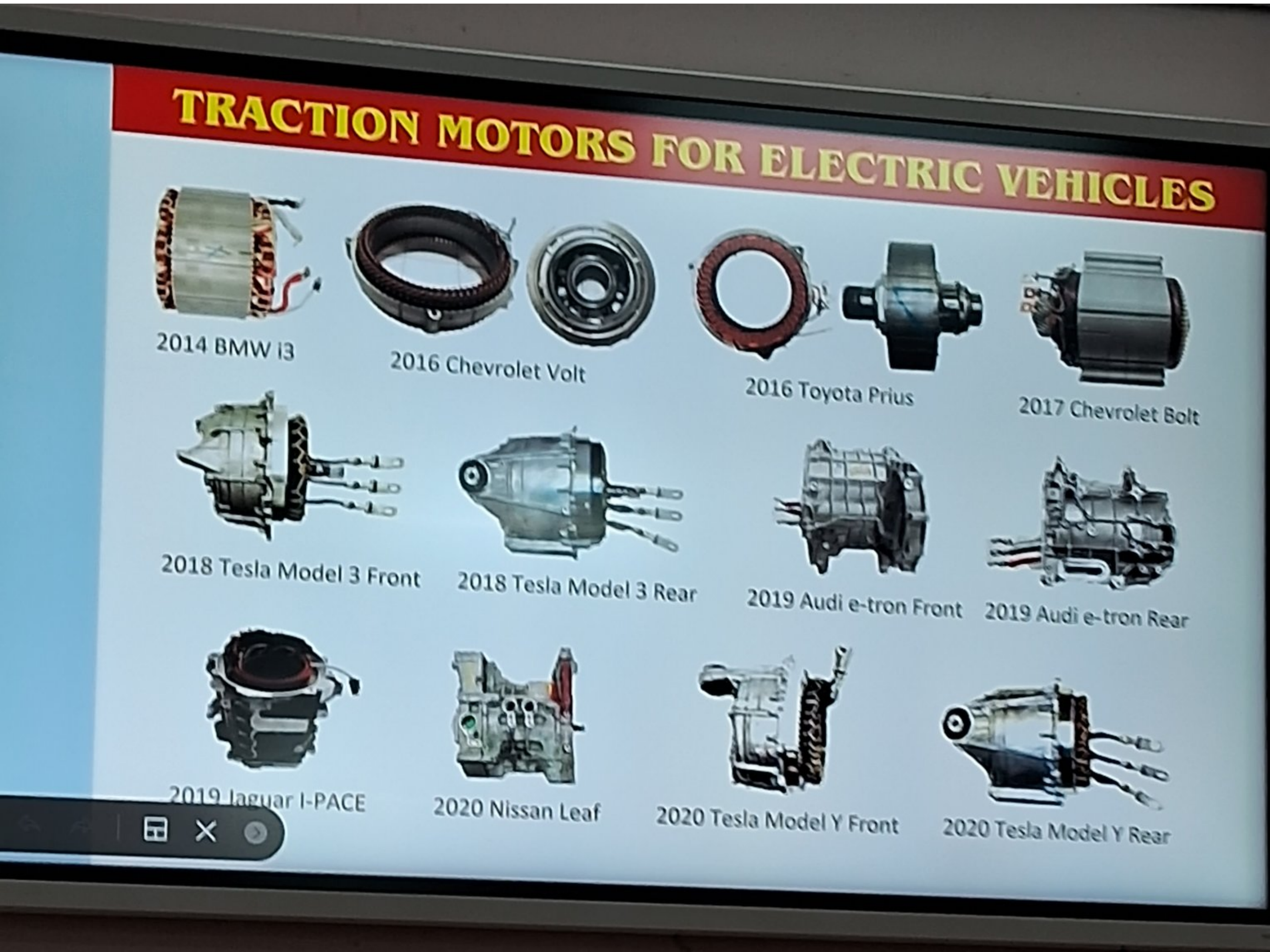


# INDUSTRIAL MOTORS vs. TRACTION MOTORS

- Traction motors are different from industrial motors.
- Industrial motors are generally optimized for rated conditions.
- Traction motors are usually high-speed motors: 6,000-7,000 rpm.
- Traction motors are designed for:


MOTORS FOR ELECTRIC VEHICLES
Motor Drives
DC
AC

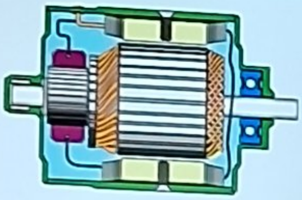

MOTORS FOR ELECTRIC VEHICLES
Motor Drives
DC
AC
Commutator
Self-Excited
Separately Excited
Series
Shunt
Winding Excited
PM Excited
Commutator-less
Induction
Synchronous
PM Brushless
BLDC
PM Hybrid
Switched Reluctance
Wound Rotor
Cage Rotor
Wound Rotor
Reluctance
PM Rotor


TRACTION MOTORS FOR ELECTRIC VEHICLES
2014 BMW i3
2016 Chevrolet Volt
2016 Toyota Prius
2017 Chevrolet Bolt
2018 Tesla Model 3 Front
2018 Tesla Model 3 Rear
2019 Audi e-tron Front
2019 Audi e-tron Rear
2019 Jaguar I-PACE
2020 Nissan Leaf
2020 Tesla Model Y Front
2020 Tesla Model Y Rear

# MOTORS FOR ELECTRIC VEHICLES

Motors used in EVs.

- Brushless DC Motor (BLDCM)
- Permanent Magnet Synchronous Motor (PMSM)
- Induction Motors (IM)
- Switched Reluctance Motors (SRM)


DC Motor


PMSM


Induction Motors


SRM

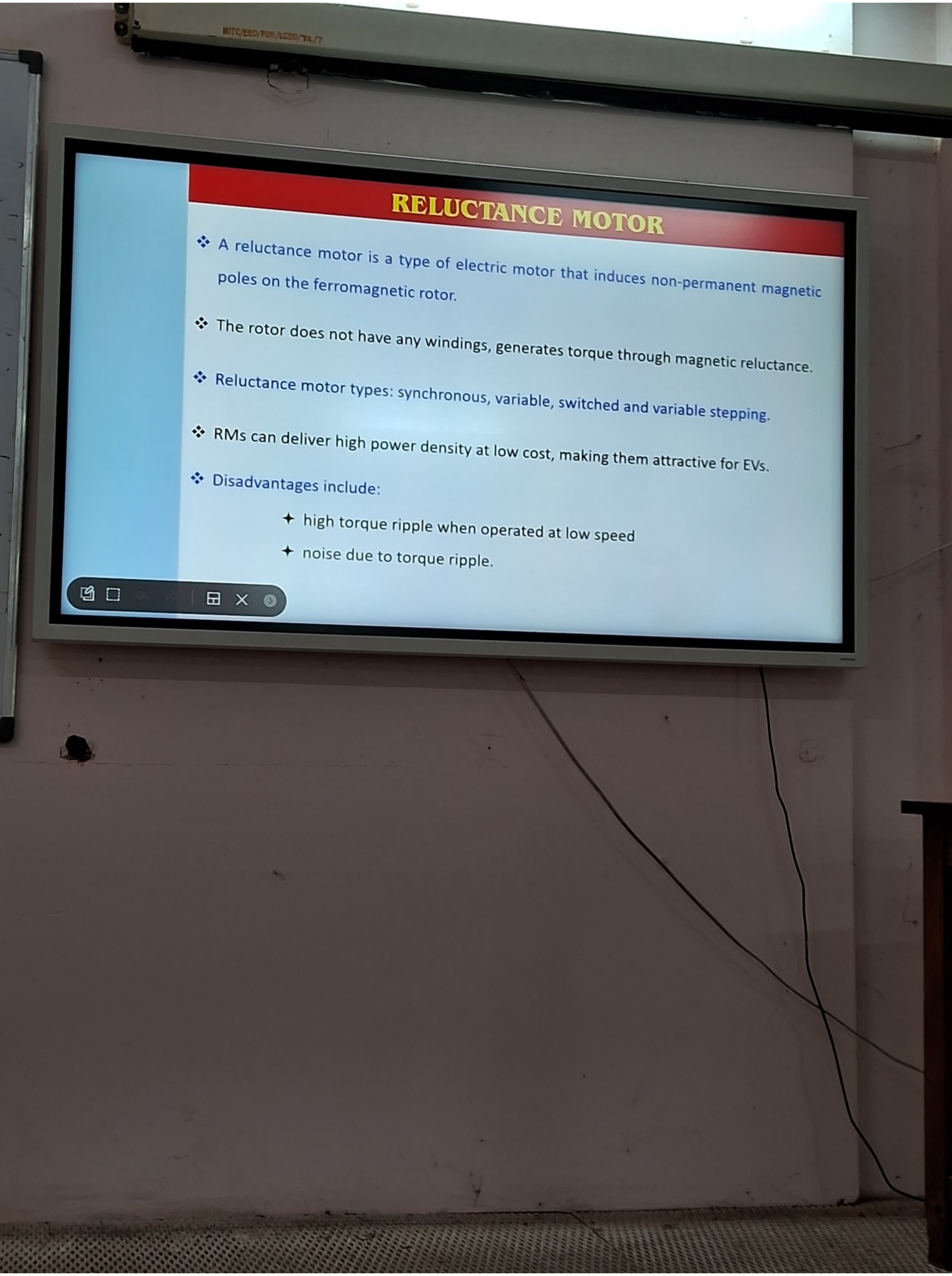
# MOTORS FOR ELECTRIC VEHICLES

❖ Popular EV motors: Permanent Magnet motors and Induction motors.

| Permanent Magnet Motors (PMM) | 3-phase AC |
|---|---|
| ❖ High power density | ❖ Very expensive |
| ❖ High torque | ❖ Suffer magnet demagnetization under high temperature |
| ❖ Very high efficiency | |

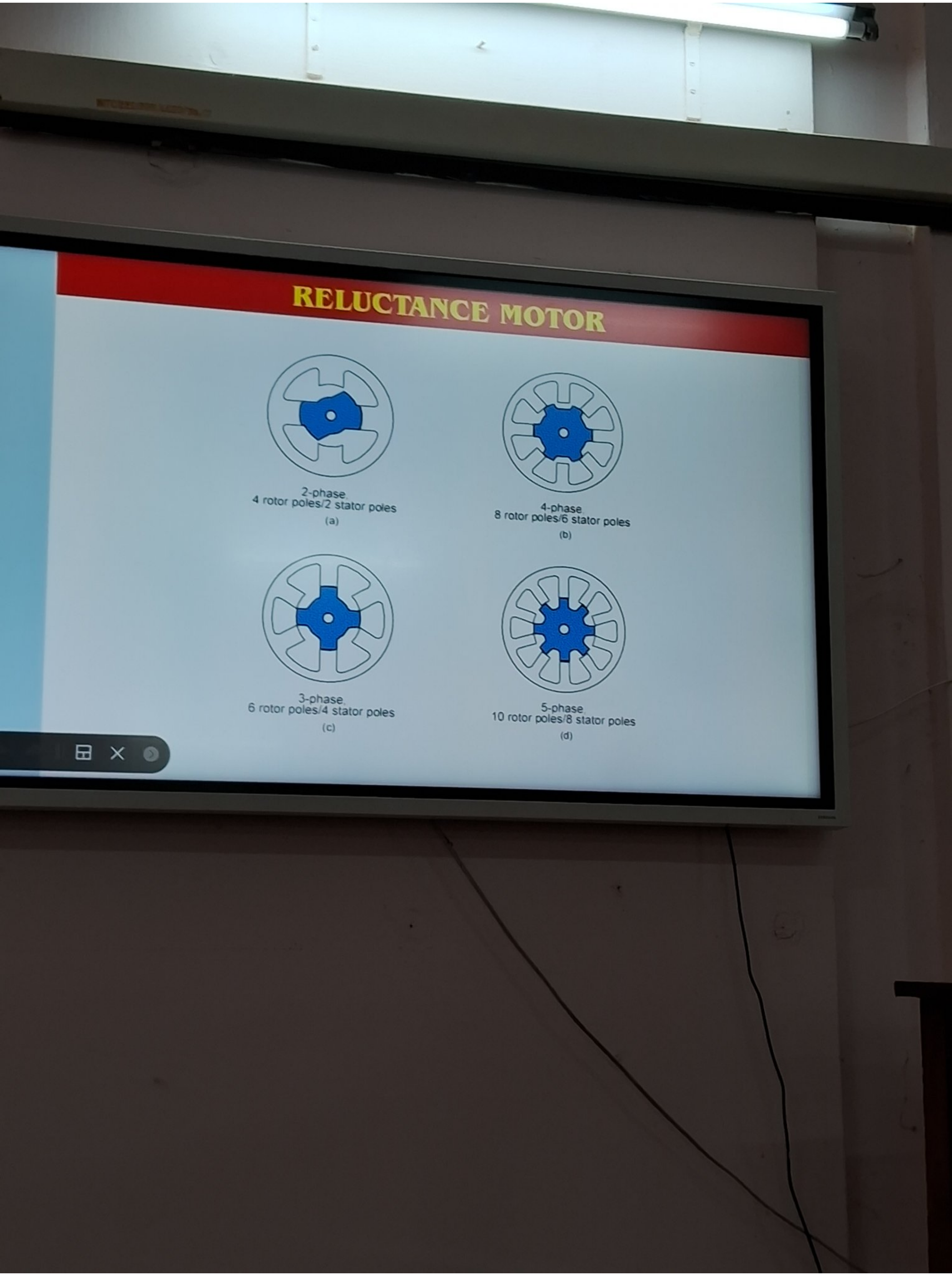
| Induction Motors (IM) | 3-phase AC |
|---|---|
| ❖ Relatively cheaper | ❖ Low power density |
| ❖ Simple design | ❖ Low efficiency |

| Switched Reluctance Motors (SRM) | DC |
|---|---|
| ❖ Simple and rugged construction | ❖ High torque ripple and acoustic noise |
| ❖ Ability of extremely high-speed | ❖ Due to high speed there will be high mechanical loss |
| ❖ Can operate with extremely long constant power range | ❖ Expensive |


RELUCTANCE MOTOR
A reluctance motor is a type of electric motor that induces non-permanent magnetic poles on the ferromagnetic rotor.
The rotor does not have any windings, generates torque through magnetic reluctance.
Reluctance motor types: synchronous, variable, switched and variable stepping.
RMs can deliver high power density at low cost, making them attractive for EVs.
Disadvantages include:
high torque ripple when operated at low speed
noise due to torque ripple.

# RELUCTANCE MOTORS

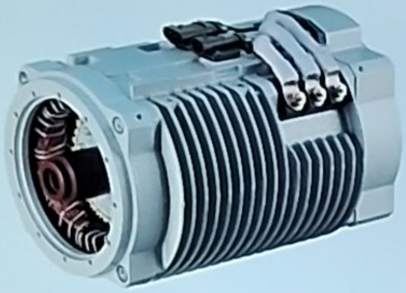
- Works on the principle of a stepper motor.
- Rotates through fixed angle (step angle) when input pulse is applied.
- A magnetic material suspended in a magnetic field aligns in the direction of the magnetic field and produces a torque.
- Speed proportional to pulse frequency:
  - Pulse < 200 Hz → discrete rotation
  - Pulse > 16 kHz → continuous rotation

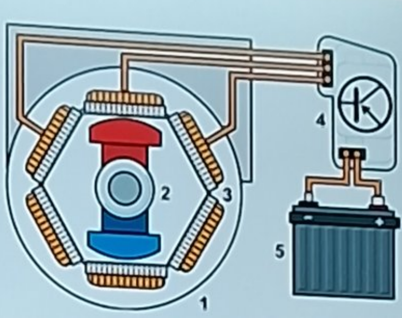

RELUCTANCE MOTOR
2-phase,
4 rotor poles/2 stator poles
(a)
4-phase,
8 rotor poles/6 stator poles
(b)
3-phase,
6 rotor poles/4 stator poles
(c)
5-phase,
10 rotor poles/8 stator poles
(d)

# PM BRUSH-LESS DC (BLDC) MOTORS

- By using high-energy permanent magnets as field excitation, a brush-less DC motor can have high power density, high speed, and high efficiency.
- These motors are very efficient because
  - No rotor power consumption due to permanent magnets for excitation
  - Absence of commutator and brushes means low mechanical friction losses
- Compactness: Due to high-energy density rare-earth magnets, high flux densities can be achieved leading to small and light motors delivering high torques.
- Ease of control: A BLDC motor can be controlled as easily as a DC motor because the control variables are easily accessible and constant throughout the operation.
- Ease of cooling: Since there is no rotor current flow, a BLDC motor rotor does not heat up. Only stator produces heat, which can be easily cooled unlike rotor).

# INDUCTION MOTORS FOR ELECTRIC VEHICLES

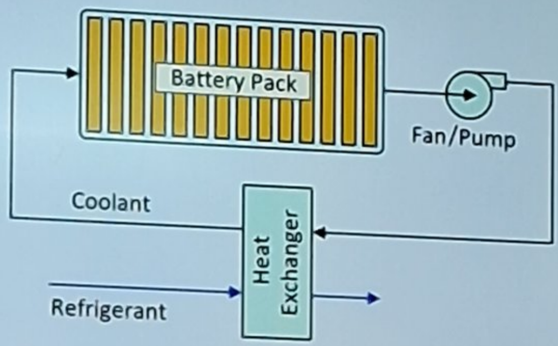




- Induction motors (IM) are less expensive than comparable size DC motors.
- IMs do not have collectors & brushes and hence, they need less maintenance.
- Weight of a IM is less than that of a DC motor for the same power.
- It is more robust than DC motors and tolerant to harsh conditions.
- Available in large voltage ranges and speed ranges.

# COOLING SYSTEM IN ELECTRIC VEHICLES

- High power traction motors need dedicated cooling systems.
- A motor driven pump circulates coolant through the inverter, motor and radiator.



# ELECTRIC VEHICLE BATTERY CHARGING

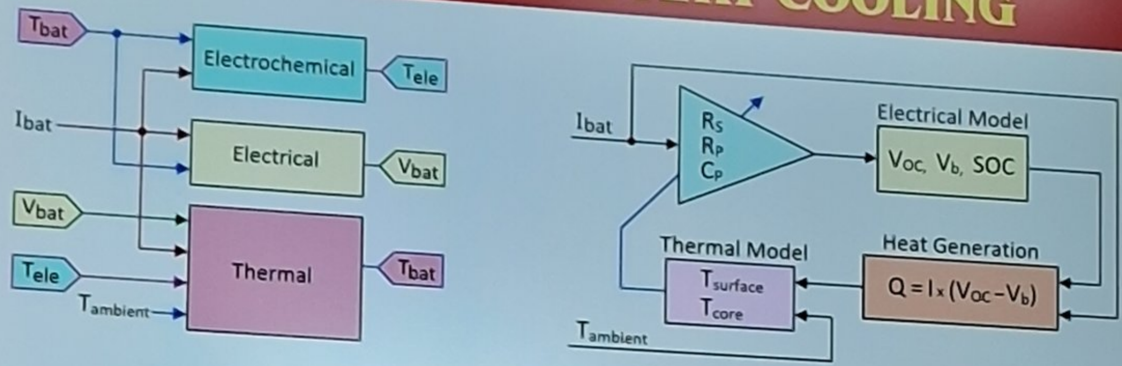
**On-Board (converter inside)**

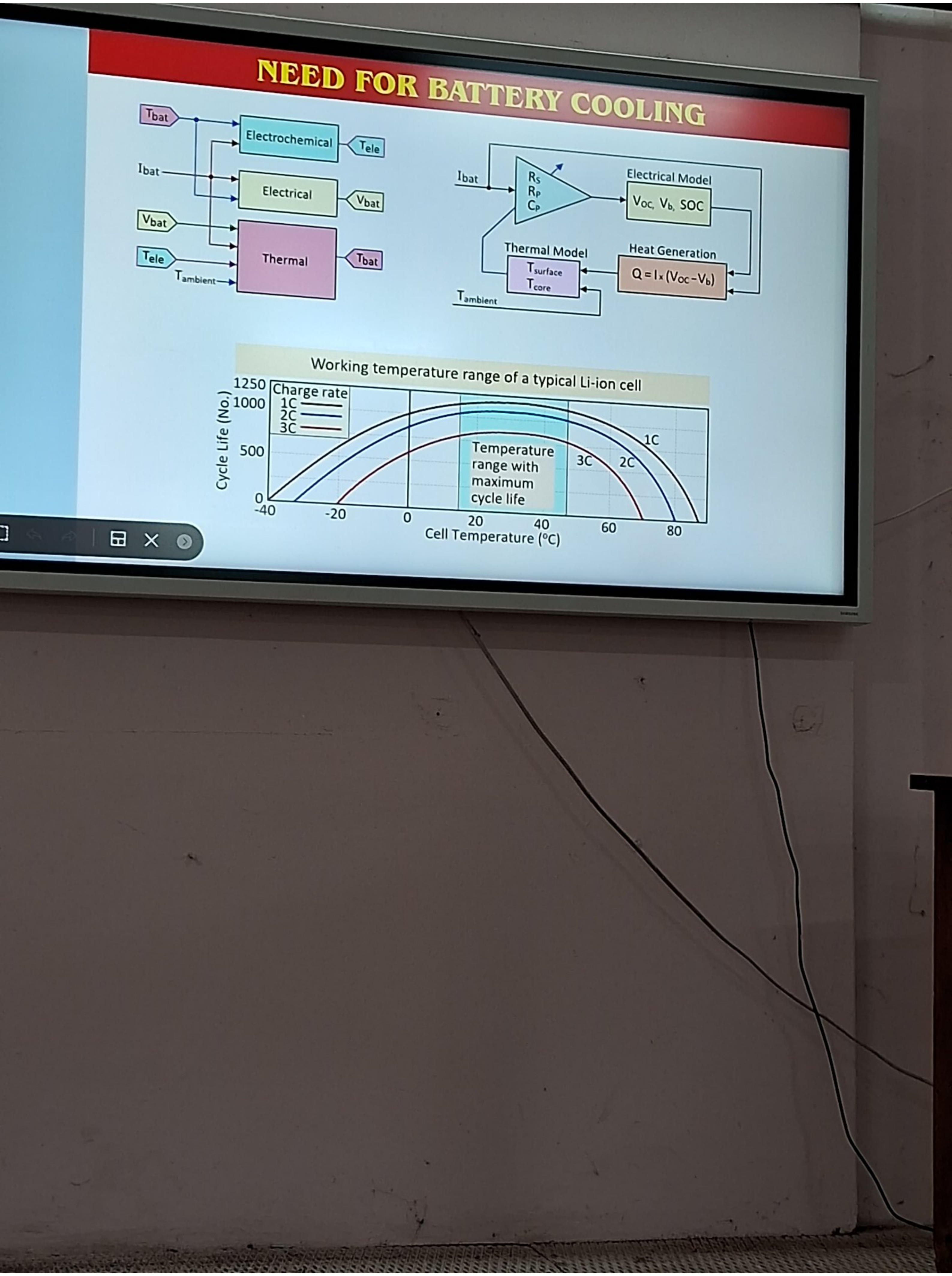
- Low energy transfer rate
- Standard BMS
- Less concern about battery heating
- Converter adds weight to vehicle
- Operated by simple pilot signal

# IMPACTS OF BATTERY FAST CHARGING

| | | Mahindra e-Verito | | | Hyundai Kona | |
|---|---|---|---|---|---|---|
| Battery Capacity | | 20 | kWh | | 40 | kWh |
| Battery Voltage | | 72 | V | (LV) | 360 | V (HV) |
| Battery Ah Rating | | 277.8 | Ah | | 111.1 | Ah |
| Battery Current at | 1C | 277.8 | A | Charging Time: 1 hr. | 111.1 | A |
| | 2C | 555.6 | A | Charging Time: 30 min. | 222.2 | A |
| | 4C | 1111.1 | A | Charging Time: 15 min. | 444.4 | A |
| | 0.5C | 138.9 | A | Charging Time: 2 hr. | 55.6 | A |
| Battery Resistance | | 0.1 | Ω | | 0.1 | Ω |
| Heat Generated at | 1C | 7.7 | kW | | 1.24 | kW |
| | 2C | 30.9 | kW | | 4.94 | kW |
| | 4C | 123.5 | kW | | 19.75 | kW |
| | 0.5C | 1.9 | kW | | 0.31 | kW |

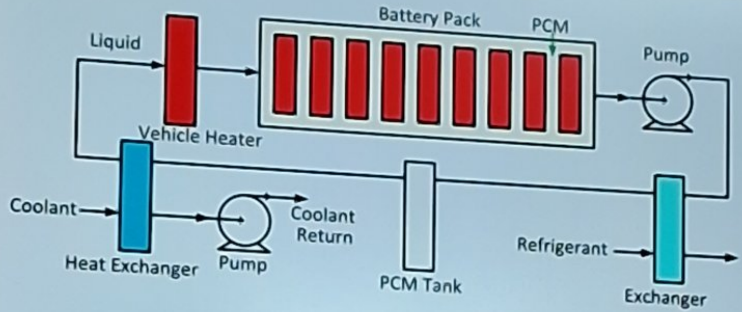
# NEED FOR BATTERY COOLING

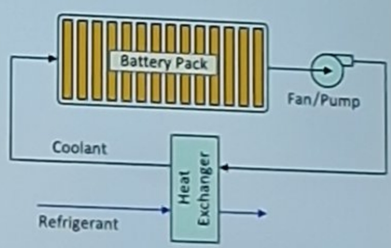




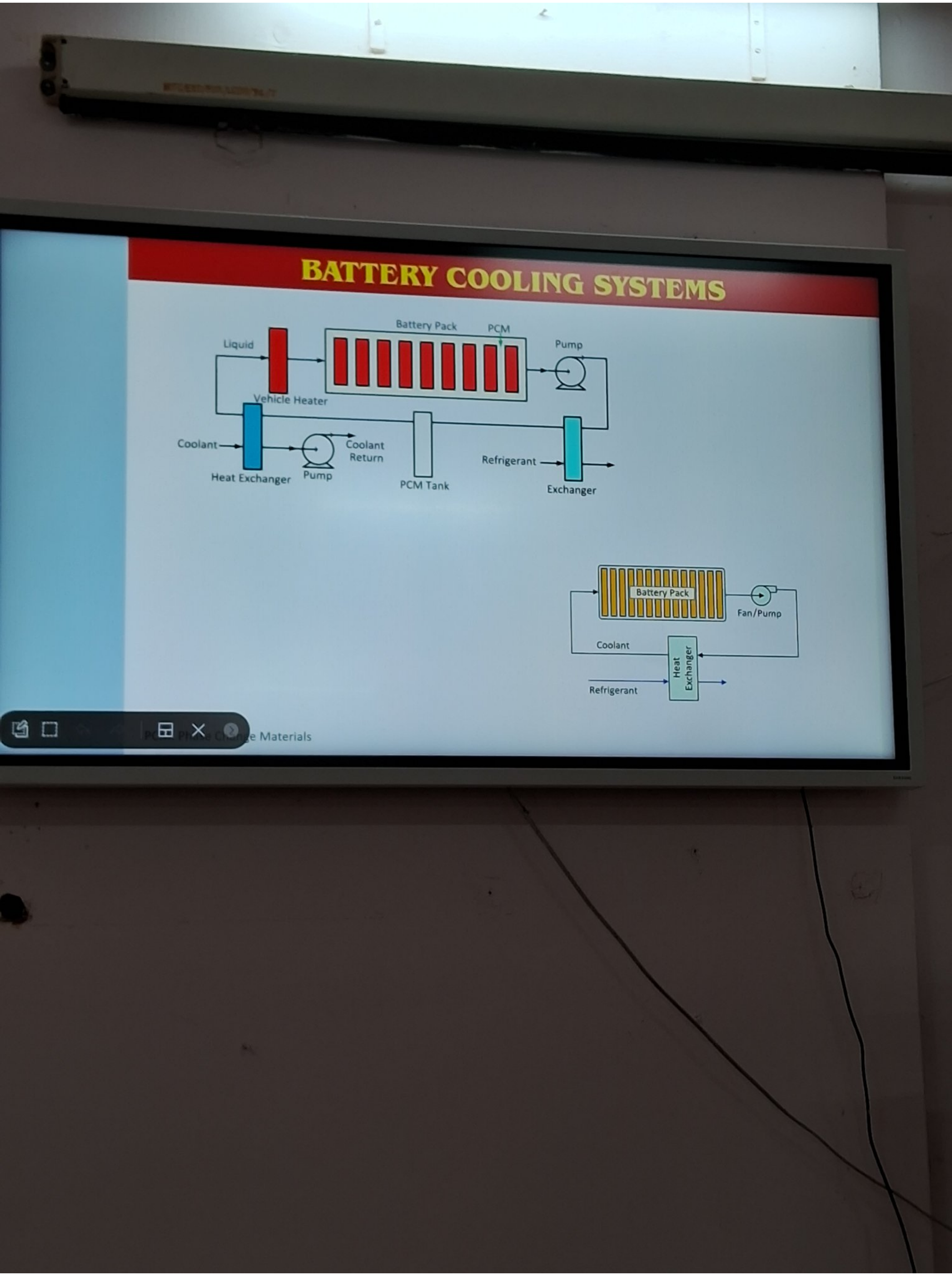
NEED FOR BATTERY COOLING
Tbat
Electrochemical
Tele
Ibat
Electrical
Vbat
Vbat
Tele
Thermal
Tbat
Tambient
Ibat
RS
RP
CP
Electrical Model
VOC, Vb, SOC
Thermal Model
Tsurface
Tcore
Heat Generation
Q = I x (VOC - Vb)
Tambient
Working temperature range of a typical Li-ion cell
Charge rate
1C
2C
3C
Cycle Life (No.)
1250
1000
500
0
-40
-20
0
20
40
60
80
Temperature range with maximum cycle life
1C
2C
3C
Cell Temperature (°C)

# BATTERY COOLING SYSTEMS



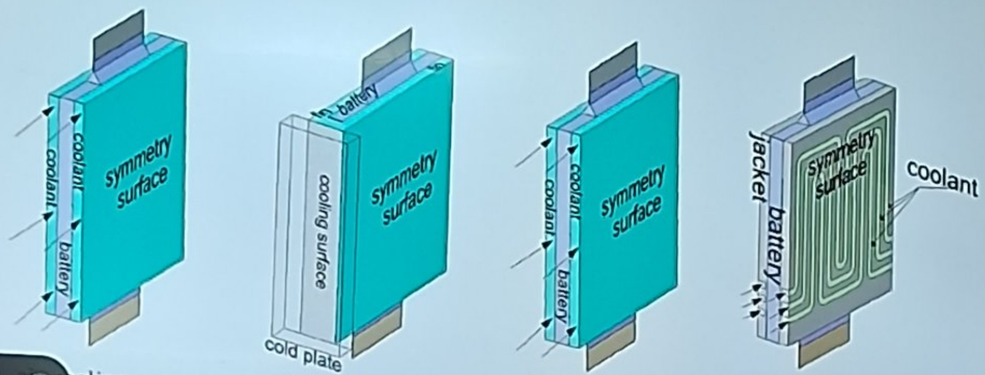

PCM: Phase Change Materials


BATTERY COOLING SYSTEMS
Battery Pack
PCM
Liquid
Pump
Vehicle Heater
Coolant
Coolant
Return
Refrigerant
Heat Exchanger
Pump
PCM Tank
Exchanger
Battery Pack
Fan/Pump
Coolant
Heat
Exchanger
Refrigerant
Materials

# EV BATTERY COOLING METHODS

Standard cooling methods for EV batteries:

- Air Cooling
- Fin Cooling
- Direct Liquid Cooling
- Indirect Liquid Cooling




a[illegible]oling | fin cooling | direct liquid cooling | indirect liquid cooling

# MONITORING OF BATTERY PERFORMANCE

- A typical EV battery pack contains many hundreds to few thousands of small cells.
- Individual cells in a pack will not be at the same performance level due to deviations in operating conditions, temperature, internal resistance, dendrite growth, age etc.
- Thus, cells will have different voltages during charge/discharge cycles.
- Weaker cells become overstressed during charging and discharging, causing them to become more weaker, until they fail completely.
- Cell balancing is a method of compensating the weaker cells by equalizing the charge on all the cells in the pack and thus helps to prevent battery premature failures.