Universität Stuttgart
Institut für Elektrische Energiewandlung

Inductive Electric Excited Synchronous Machine

An Option for Future Mobility

Prof. Dr.-Ing. Nejila Parspour

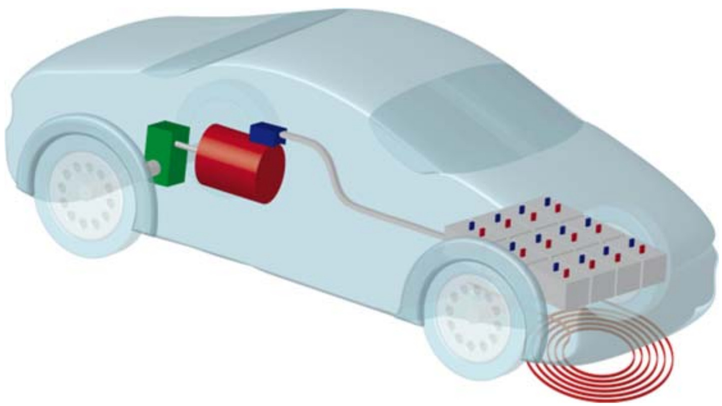
iew

modern societies
need
modern mobility concepts

mobility concepts should be environmentally friendly and resource-efficient

electro mobility as an alternative solution!

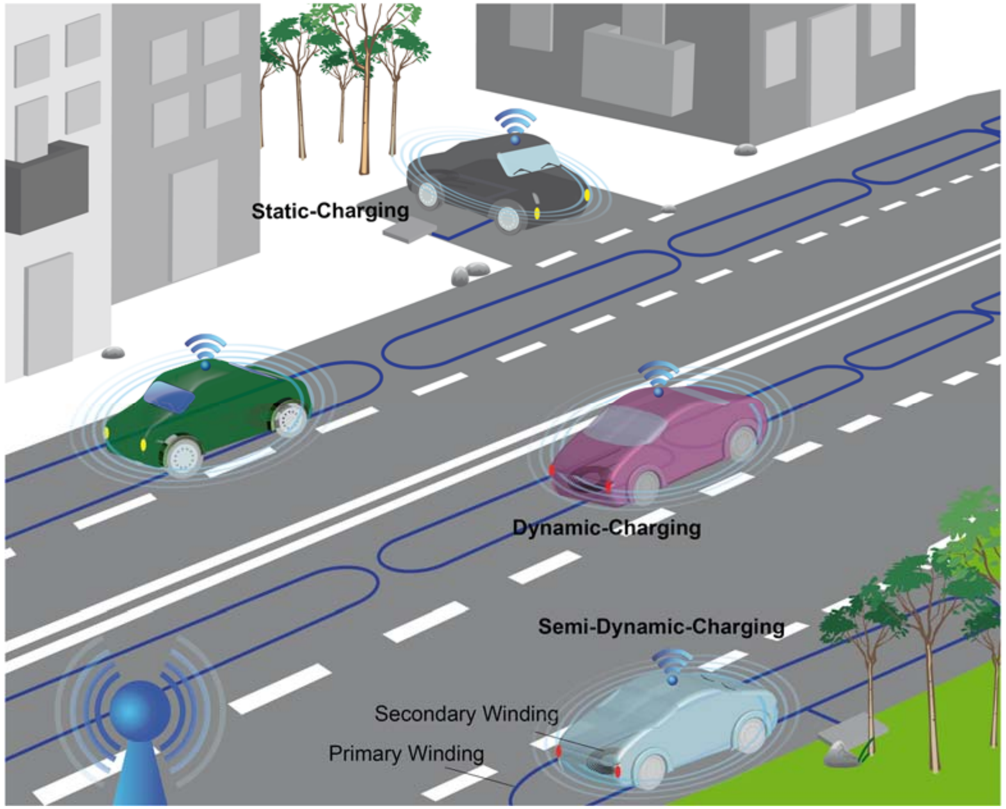
Battery electric vehicle



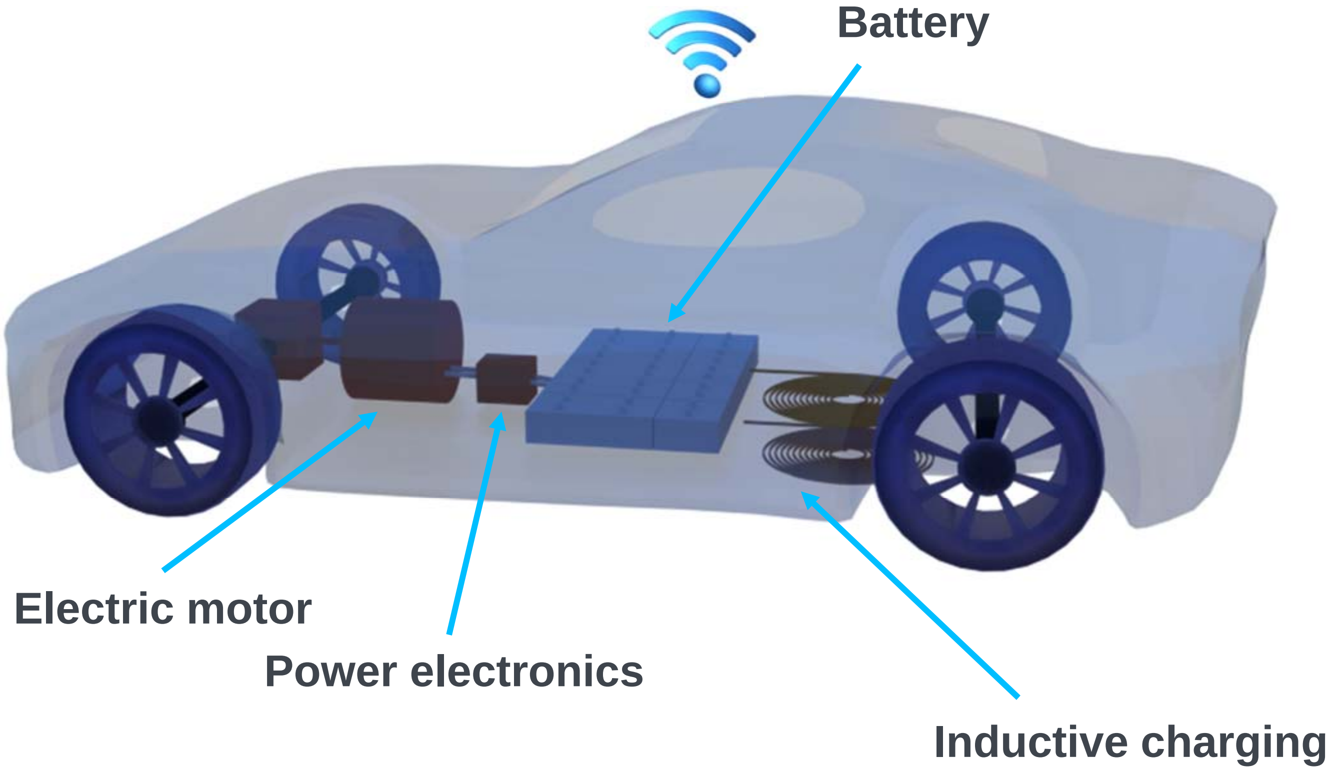
- Zero emissions at the tailpipe
- Low noise level
- Globally emission-free if electricity is generated with renewable resources

- Electric motors have higher efficiency than combustion engines
- BEVs are powered by electricity and require no fuels
- Increased dynamics and driving pleasure
- Straightforward powertrain in comparison to hybrid electric vehicles
- Electric vehicles can be used as energy storages in vehicle-to-grid scenarios: Contribution for a better integration of renewable energy

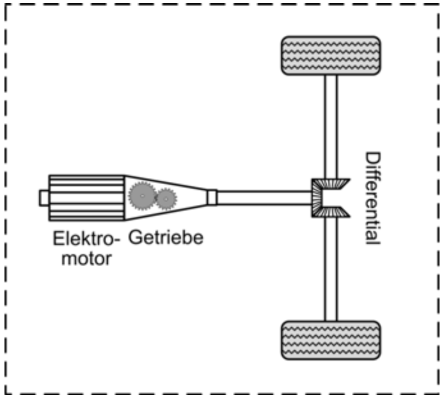
Future Mobility

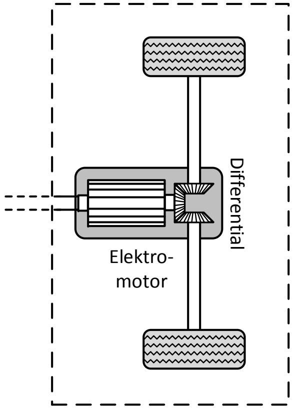


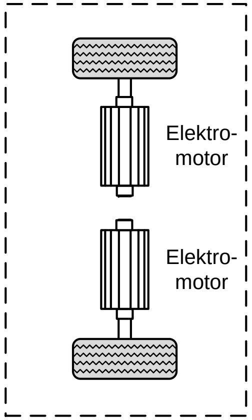
Battery electric vehicle

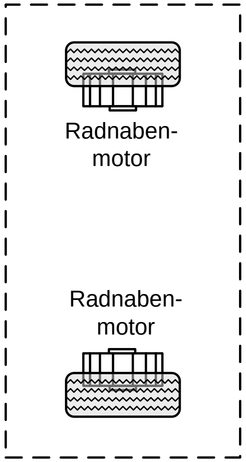


Drivetrain concepts







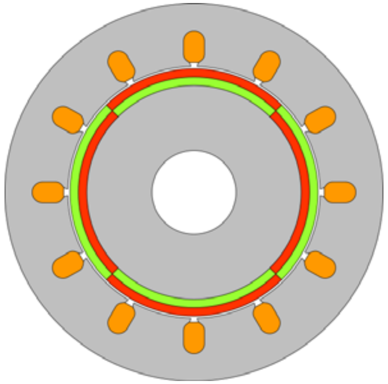


E-Motor Types

manufacturer	electric machine
BMW (i3) Citroen (C-Zero), Citroen (Berlingo Electric) Mercedes (SLS Electric Drive) Mitsubishi (Electric Vehicle) Nissan (Leaf) Peugeot (iOn) , Peugeot (Partner Electric) Renault (Kangoo Z.E.) Volkswagen (e-Up!) Volkswagen (e-Golf) Tesla (Model 3)	Permanent Magnet Excited Synchronous Machine (PMSM)
Karabag (New 500E) Renault (Twizy) Tesla (Model S)	Asynchronous Machine (ASM)
Renault (ZOE) Smart (fortwo electric drive)	Electrically Excited Synchronous Machine (EESM)

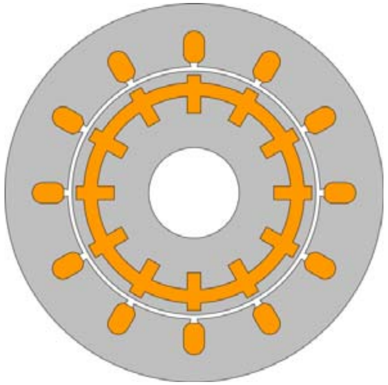
PMSM, ASM and EESM

PMSM



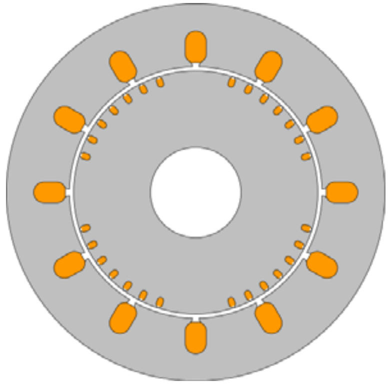
$$M_{\mathrm{i}} = \frac{3}{2} z_{\mathrm{p}} \left(\hat{\Psi}_{\mathrm{PM}} i_{1\mathrm{q}} + (L_{\mathrm{d}} - L_{\mathrm{q}}) i_{1\mathrm{d}} i_{1\mathrm{q}} \right)$$

ASM



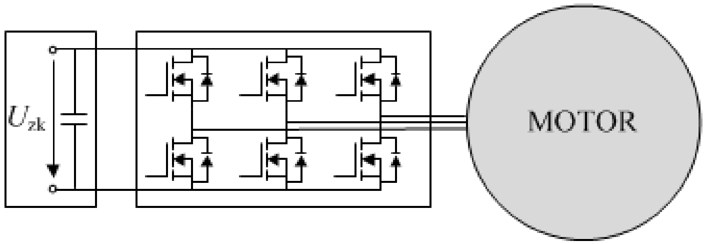
$$M_{\mathrm{i}} = \frac{3}{2} z_{\mathrm{p}} \frac{L_{\mathrm{h}}}{L'_{2}} i_{1\mathrm{q}} \Psi'_{2\mathrm{d}}$$

EESM



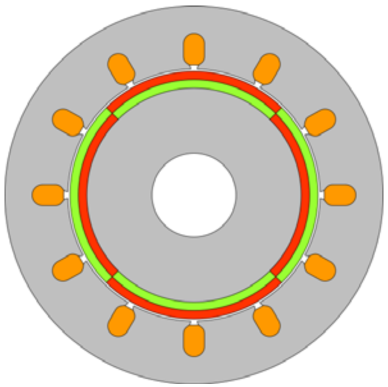
$$M_{\mathrm{i}} = \frac{3}{2} z_{\mathrm{p}} \left(M_{\mathrm{d}12} i_{2\mathrm{d}} i_{1\mathrm{q}} + (L_{\mathrm{d}} - L_{\mathrm{q}}) i_{1\mathrm{d}} i_{1\mathrm{q}} \right)$$

power electronics



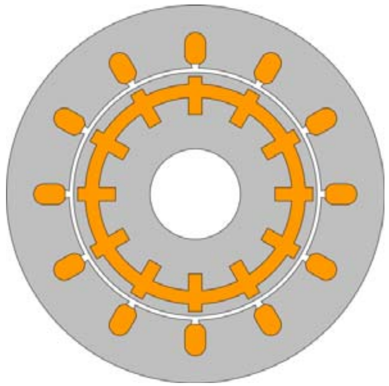
PMSM, ASM and EESM

PMSM



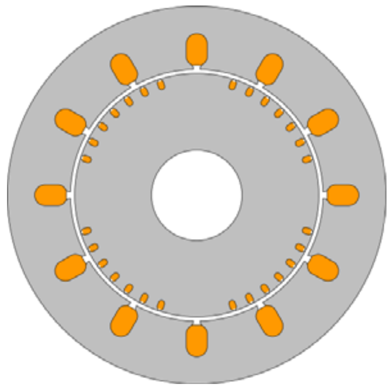
$$M_i = \tfrac{3}{2} z_p \left(\hat{\Psi}_{PM} i_{1q} + (L_d - L_q) i_{1d} i_{1q}\right)$$

ASM

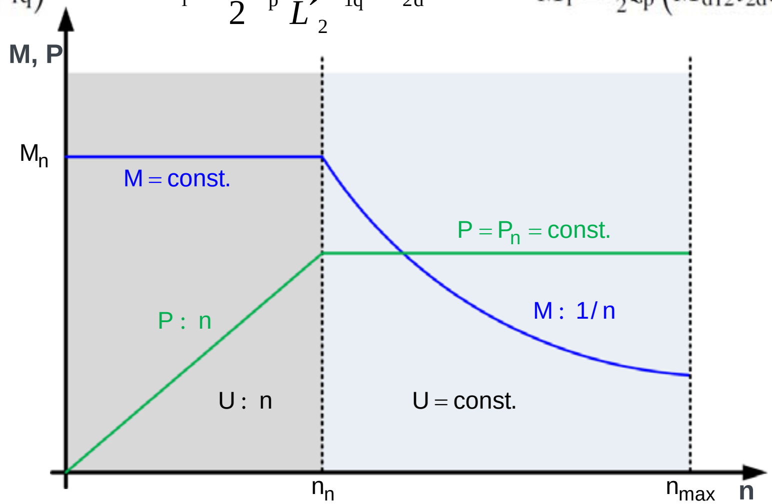


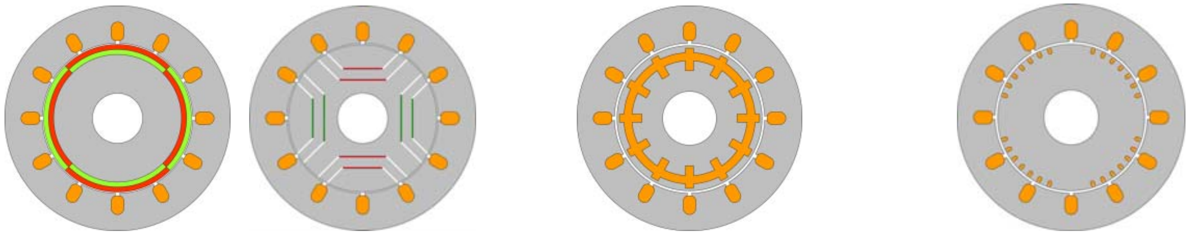
$$M_i = \frac{3}{2} z_p \frac{L_h}{L'_2} i_{1q} \Psi'_{2d}$$

EESM



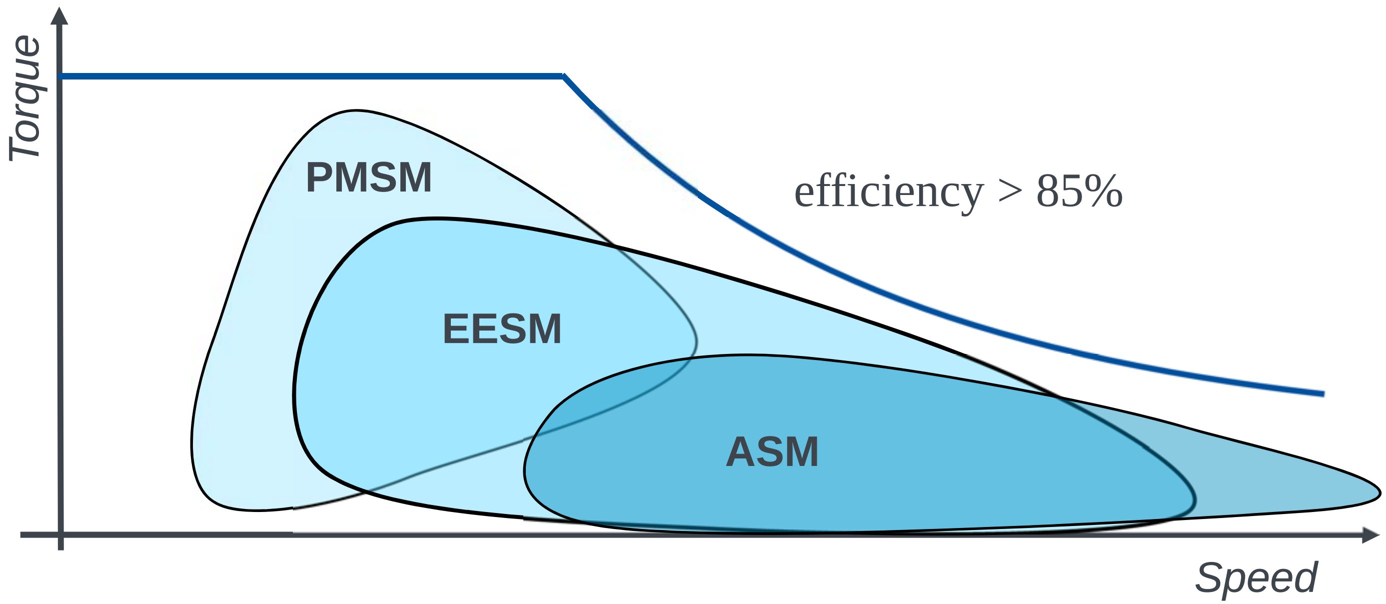
$$M_i = \tfrac{3}{2} z_p \left(M_{d12} i_{2d} i_{1q} + (L_d - L_q) i_{1d} i_{1q}\right)$$





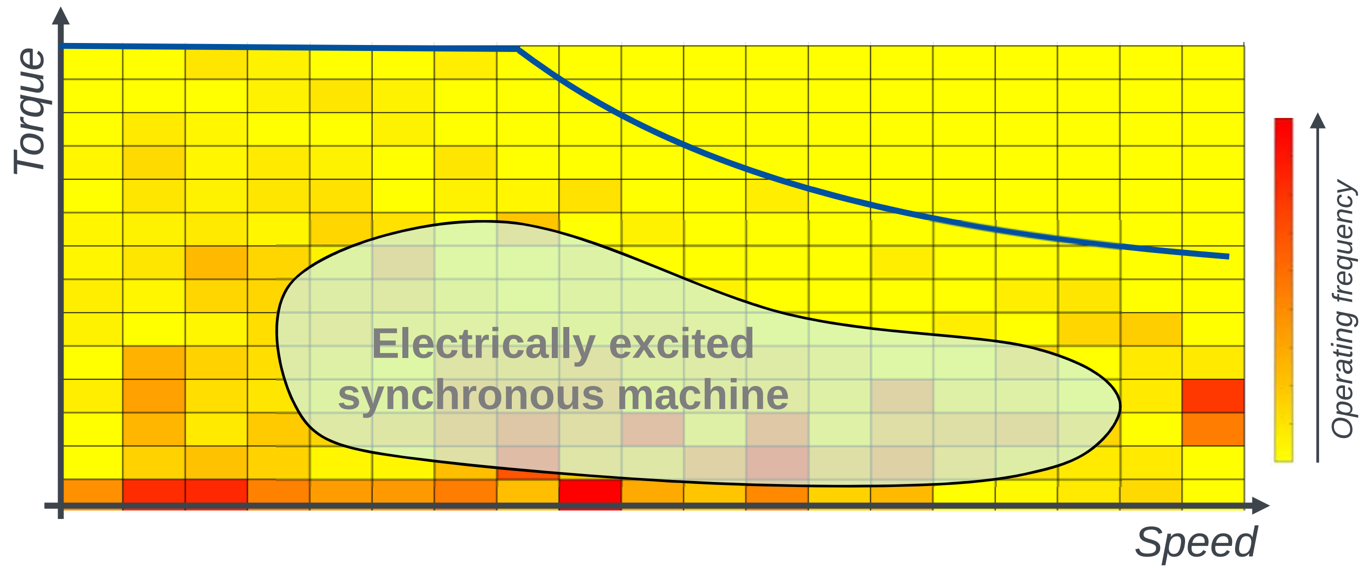
	PMSM	ASM	EESM
$n < n_n$	high efficiency	disadvantages in efficiency	good efficiency
$n > n_n$	low efficiency	advantages in efficiency	high efficiency
costs	higher production costs than ASM (magnet material)	design is simple and cheap (aluminium die-cast rotor)	Lower production costs than PMSM (no magnets)
durability	low maintenance	low maintenance	Slip rings
fault	critical (overvoltage, braking torque)	Uncritical	Uncritical
temperature sensitivity	critical (permanent magnets)	uncritical	Uncritical

PMSM, ASM and EESM Efficiency



Drive cycle

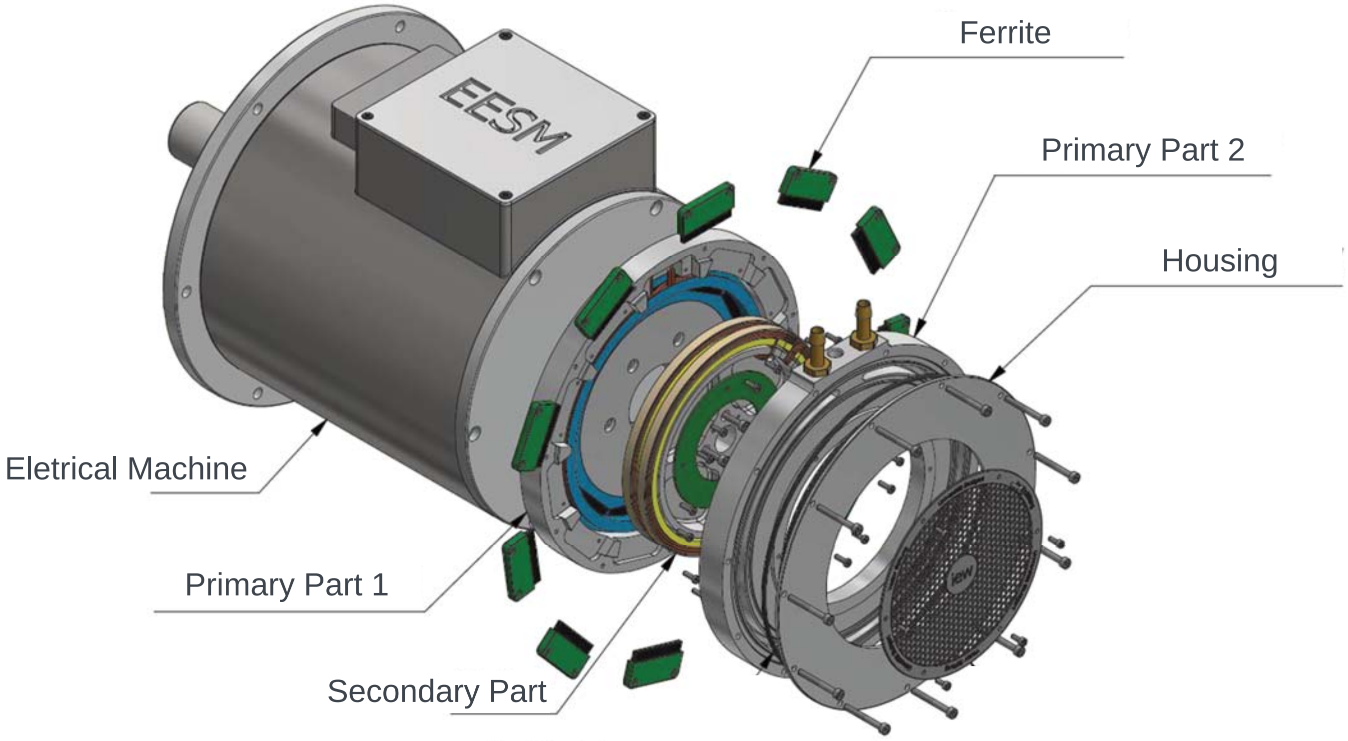
Worldwide harmonized Light vehicles Test Procedure (WLTP)



Electrically excited synchronous machine

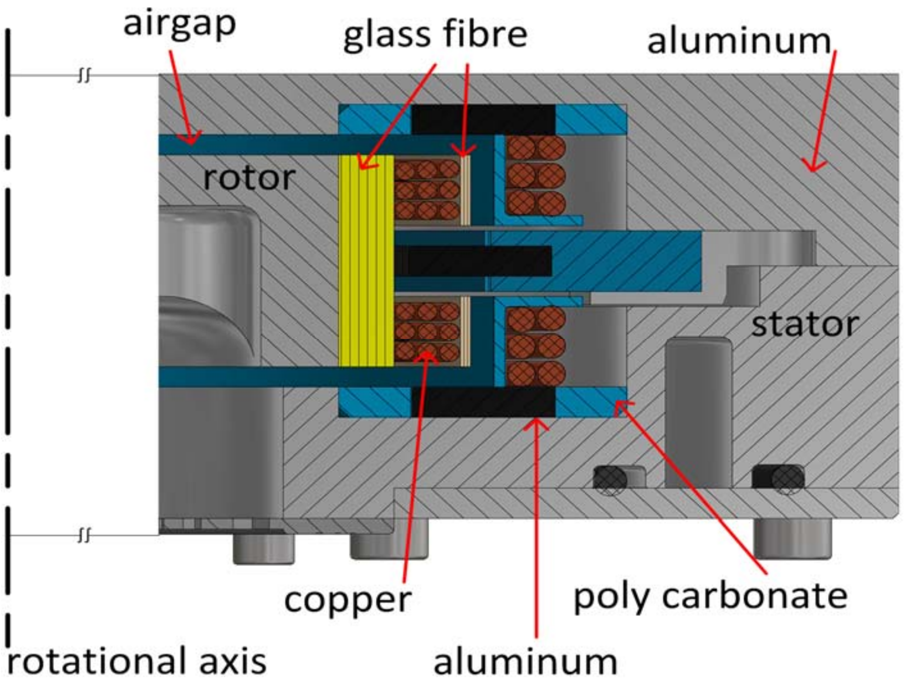
- **Advantages**
  - high efficiency
  - no expensive materials
  - High efficiency field-weakening operation
  - Safety
  - High overload possible
- **Disadvantages**
  - slip ring system
- **Solution**
  - Contactless energy transfer instead of slip rings
  - Inductive electrical synchronous machine (iEESM)

iEESM


EESM
Ferrite
Primary Part 2
Housing
Eletrical Machine
Primary Part 1
Secondary Part

iEESM

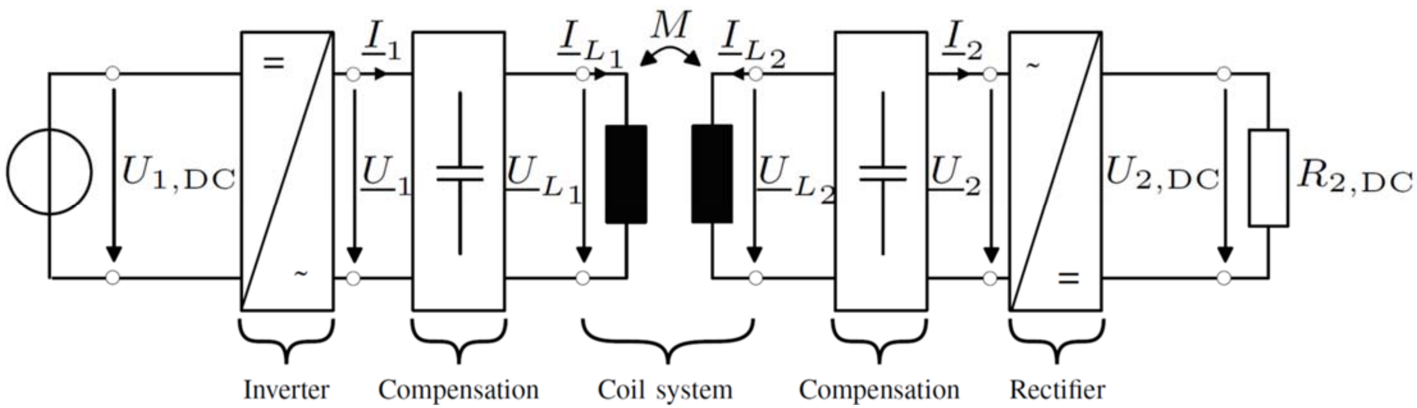
Setup of the contactless energy transfer path



- No ferrite material on the rotor
- Coupling factor independent of the position
- No centripetal force on the ferrite parts
- Glass fiber bandage around the coil
- Simple manufacturing process

iEESM

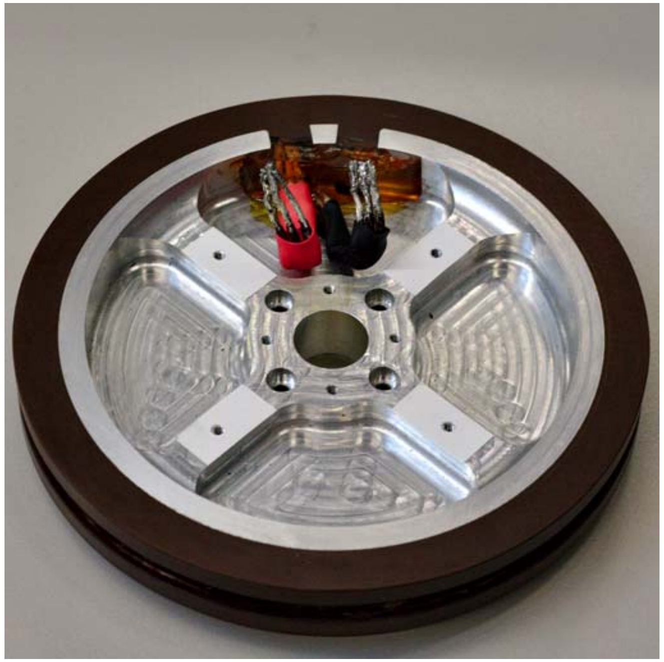
Overview of contactless energy transfer



iEESM

Secondary Part (rotating)

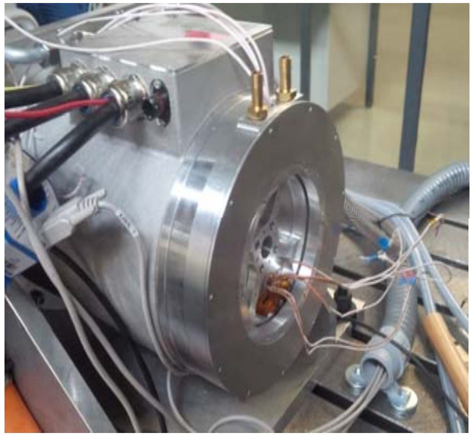
SECONDARY PART WITH WINDING AND GLASS FIRBE

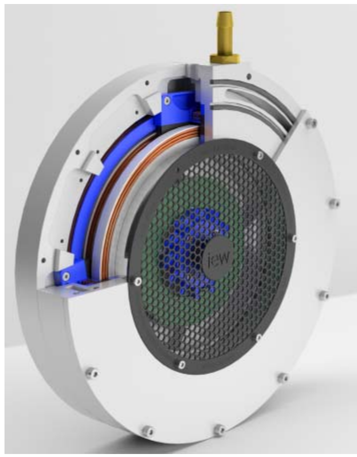


SECONDARY PART WITH POWER ELECTRONICS AND COMPENSATION

iEESM

E-Motor	60 kW
Transferred Power	800 W
Mechanical Air gap	2 mm
Frequency	200 kHz
Efficiency	85 %
Compensation	1p2p
Inverter	Royer-Converter





iEESM

Research issues

- New design of an electrical machine for an EV
- Minimization of magnetic coupling
- Integration of the CET system into the electrical machine
- Mutual influence of CET system and electrical machine
- Optimal operation points
- Dynamic operation

Concept EV

Inductive Charging

- 3 kW and 12 kW ✓
- 96 % efficiency

iEESM

- Inductive field exciting ✓
- Design of the highly integrated electrical excited synchronous machine for EVs

Thank you!