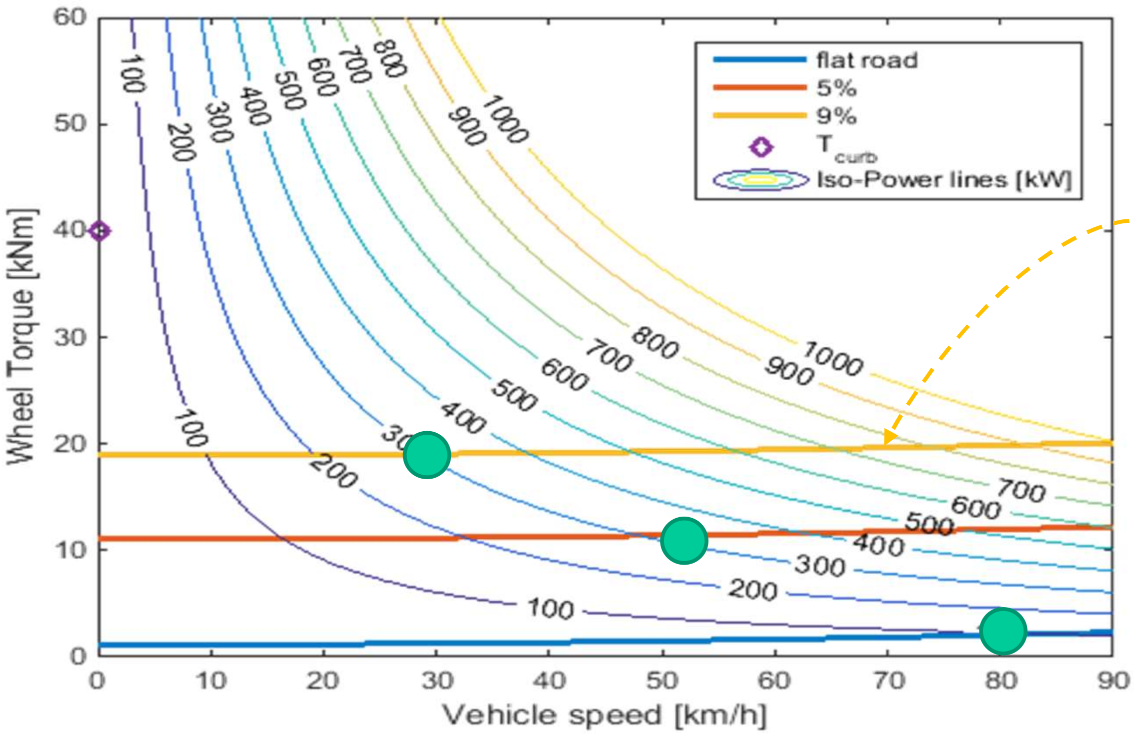
Hybrid Drive Systems for Vehicles

L9 - Cost

Vehicle requirements



$$\frac{dv}{dt} = \frac{\left(F_{tractive} + F_{road} + F_{slope}\right)}{M_v}$$

$$F_{road} = \left(C_r M_v g \cdot \cos(slope) + \frac{1}{2}\rho_a C_d A_v v^2\right)$$

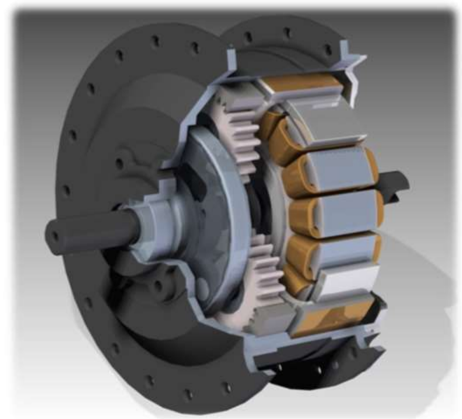
$$F_{slope} = M_v \cdot \sin(slope) \cdot g$$

$$T_{wheel} = \left(F_{road} + F_{slope}\right) \cdot r_{wheel}$$

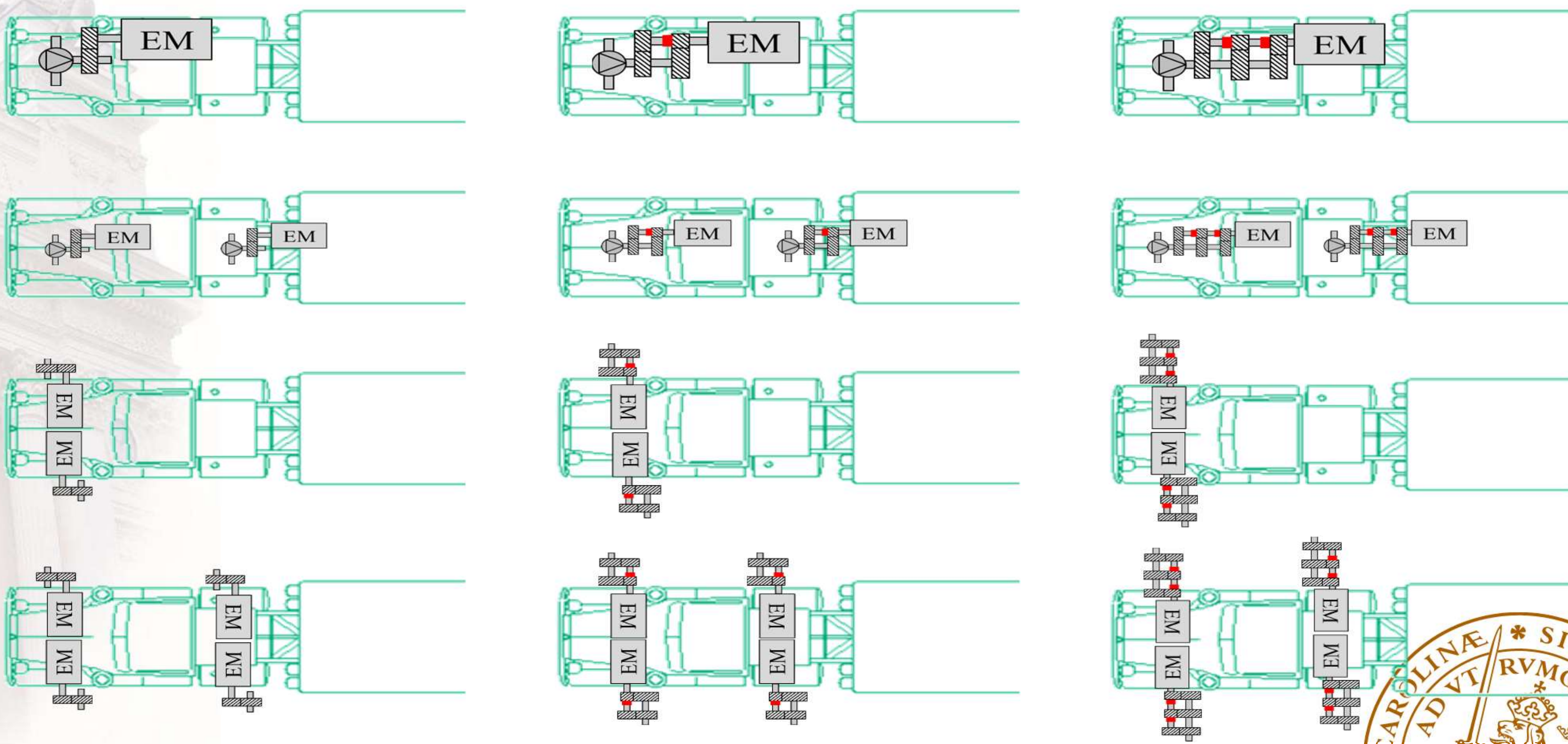
Vehicle Characteristics	
Weight	40x10^3 kg
Wheel radius	0.505 m
Front area	7.9 m^2
Drag coefficient	0.79

Powertrain components in the study

- Excluding the battery
- Including the:
  - PEC
  - Traction Machine
  - Transmission
- Almost all developed by:
  - Gabriel Dominguez (design & control)
  - Pontus Fyhr (production)
  - Former PhD students in Lund
    - *Gabriel now @ Borg Warner*
    - *Pontus now @ Haldex Brakes Products*

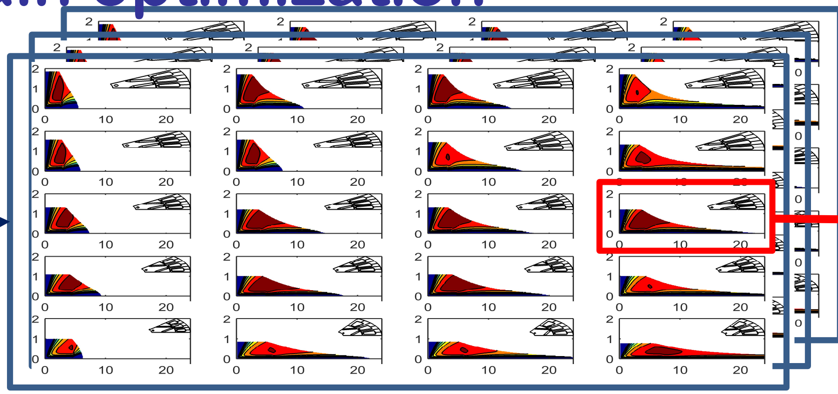


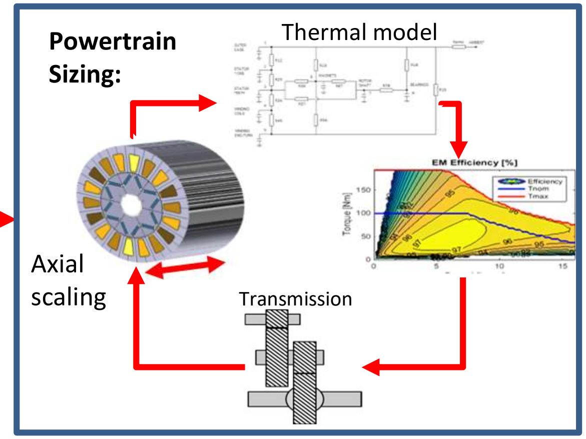
Powertrain concepts



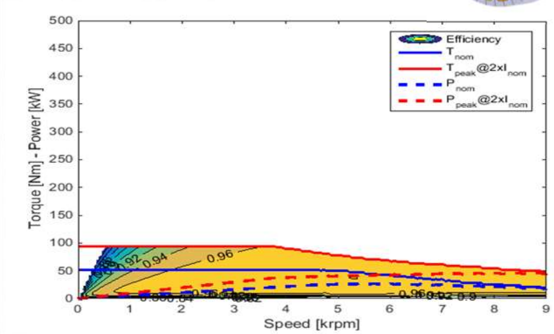
Powertrain optimization

Input data:
- Concept
- Power
- Vdc
- Fsw
- Semiconductor tech.
- Cooling temp.
- Etc.
- Perf. Req.

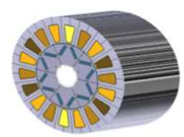


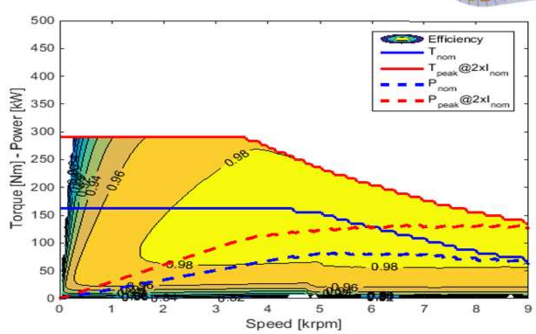


25 kW
CPSR = 1.6
Lact = 44 mm

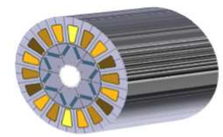


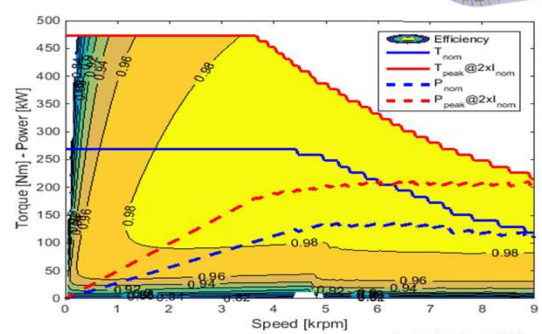
75 kW
CPSR = 1.9
Lact = 127 mm



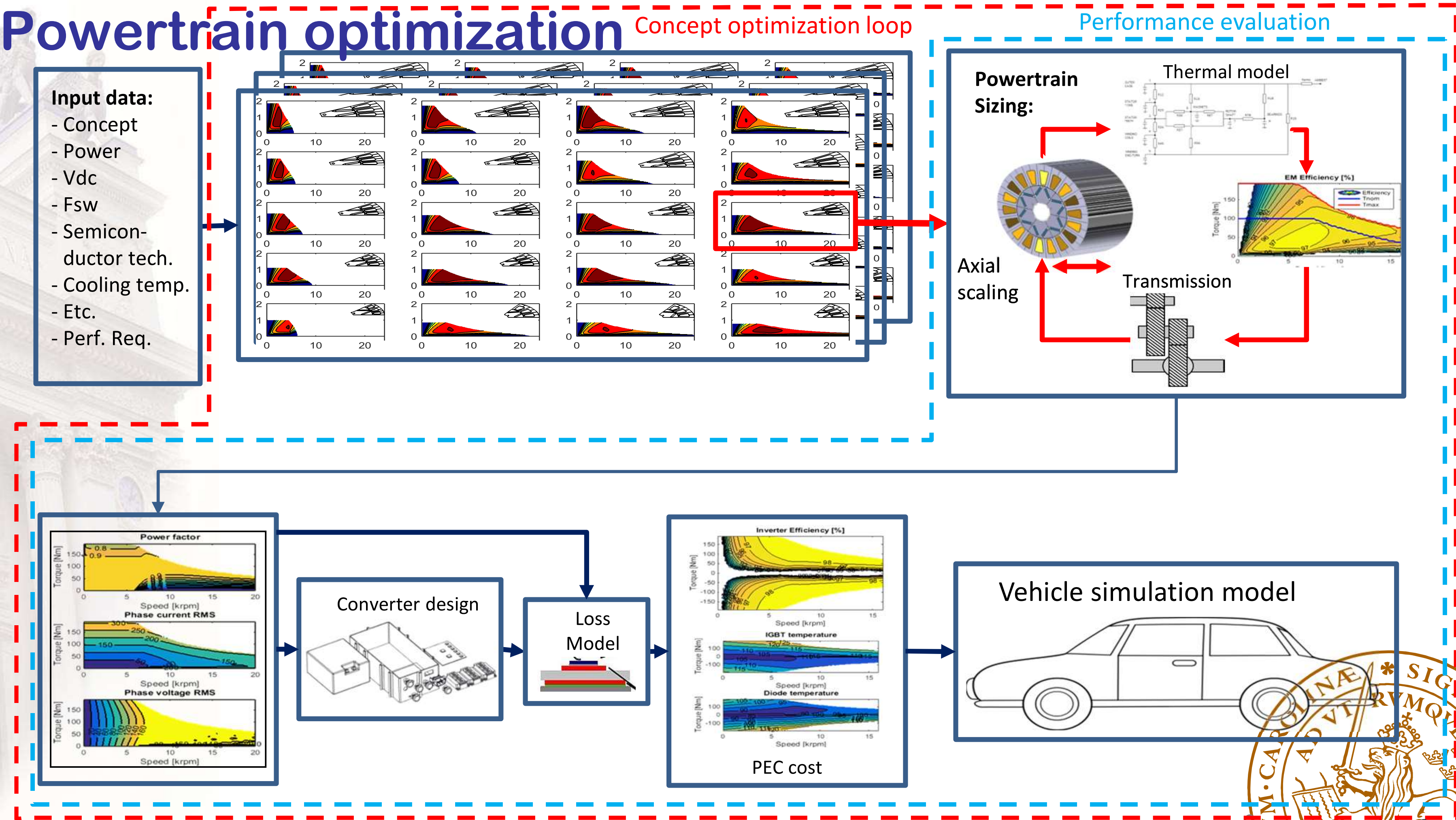


125 kW
CPSR = 2
Lact = 202 mm



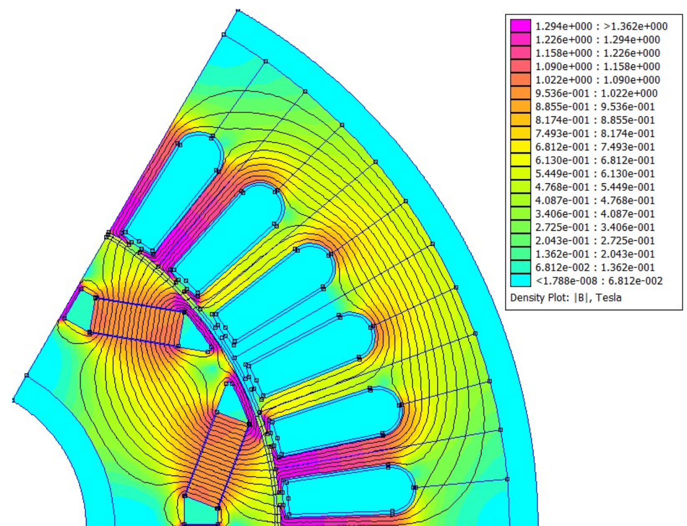


Powertrain optimization



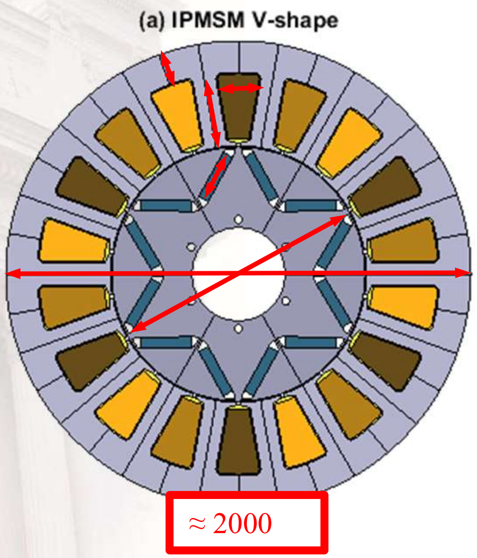
Electrical Machine: Approach and Topologies

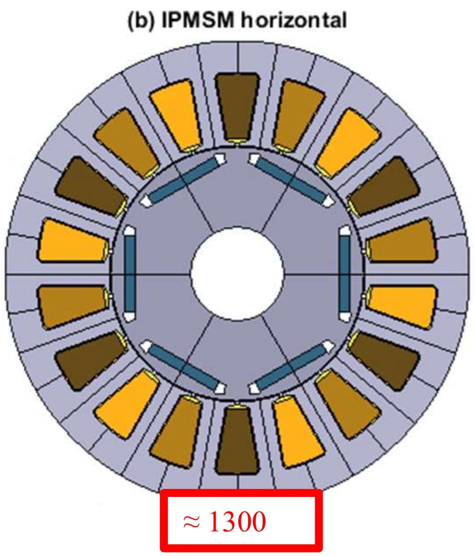
- FE are used to determine the characteristics of the EM.
- A large number of EM geometries are simulated in advance.
- The goal is to take the FE out of the optimization loop.
- Axial scaling is used to adjust the EM performance to the requirements.

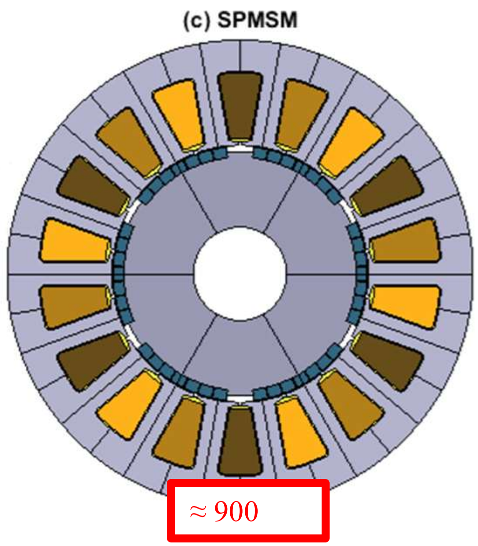


Electrical Machine: Approach and Topologies

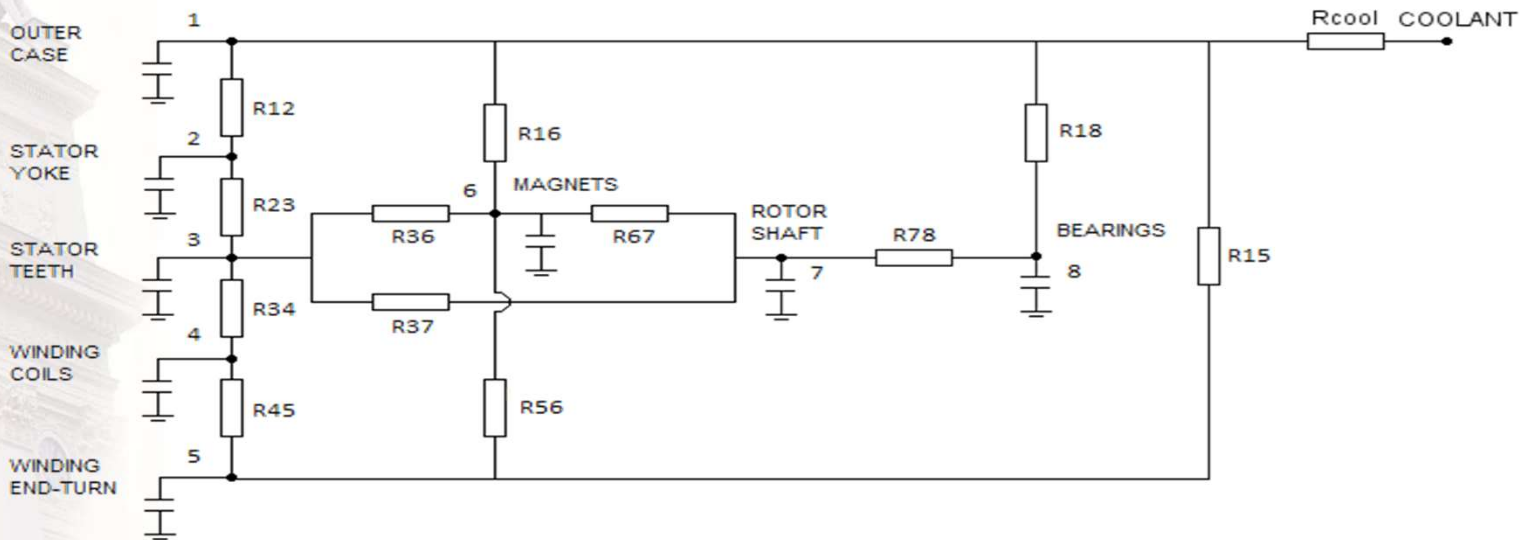
+ Number of poles
+ Number of Slots/pole/phase





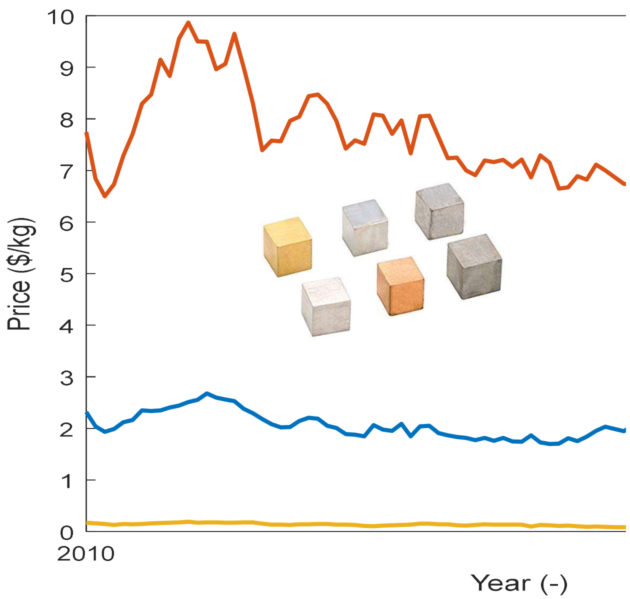


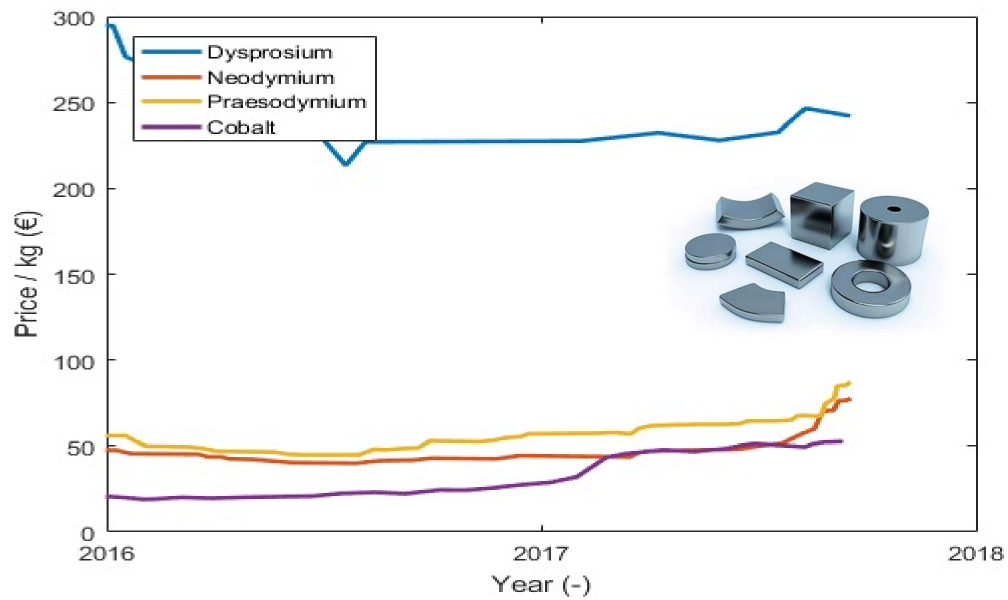
Electrical Machine: Thermal model



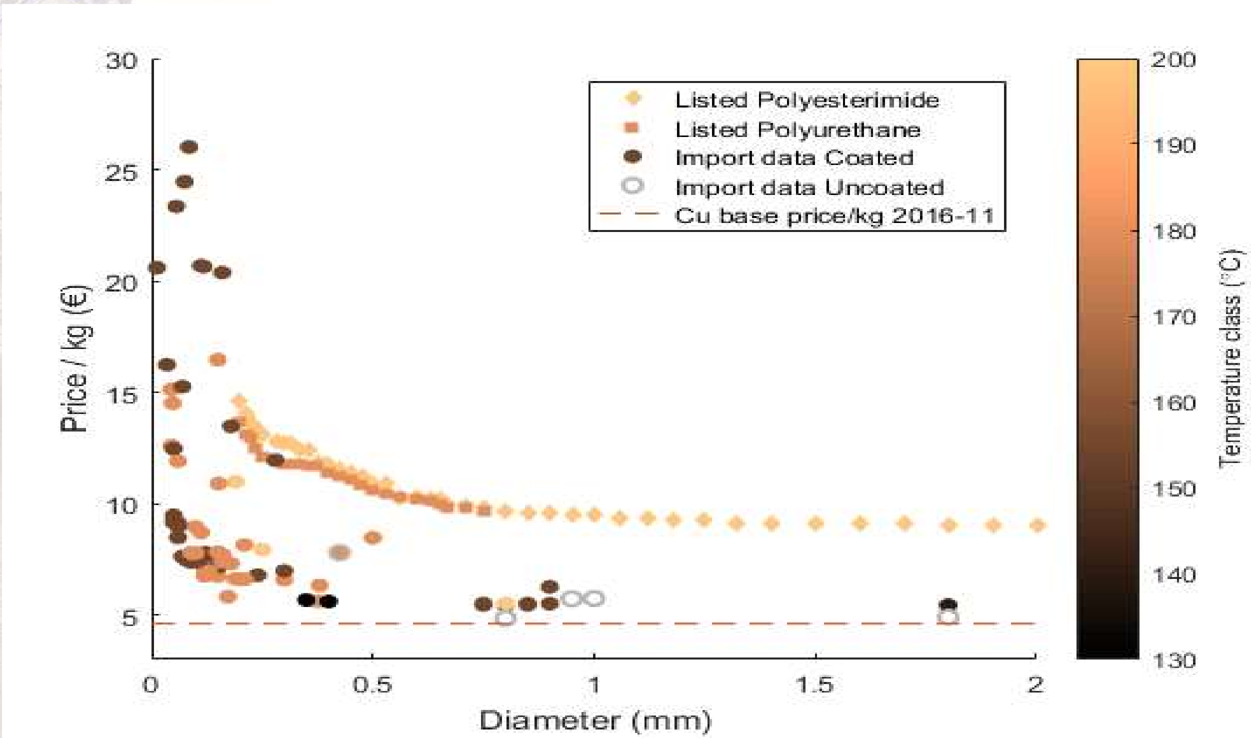
1. Simple, quick to excecute.
2. Thermal capacitances and resistances are calculated based on the geometry and materials of the machine.
3. Used for axial scaling of the EM, limitation of overloading capabilities and evaluating the thermal performance of the EM in a given drive cycle and powertrain.

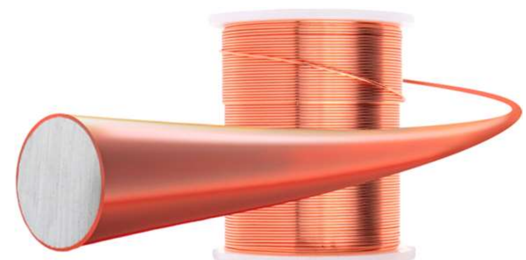
Electrical Machine: Cost – Commodities



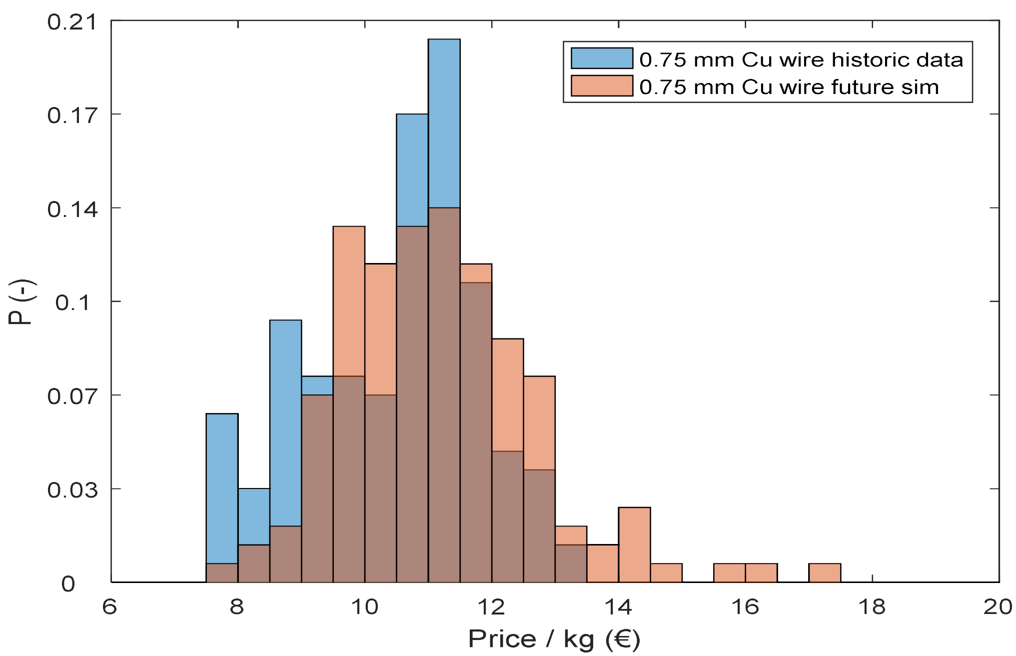


Electrical Machine Cost – Actual materials





Electrical Machine Cost – Sim materials



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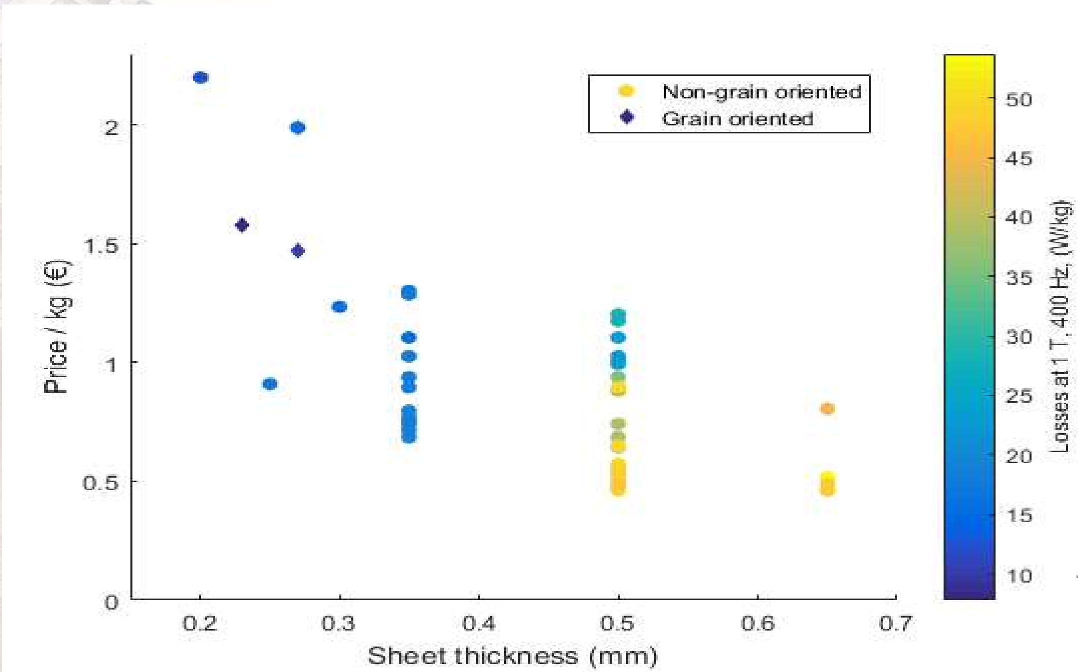
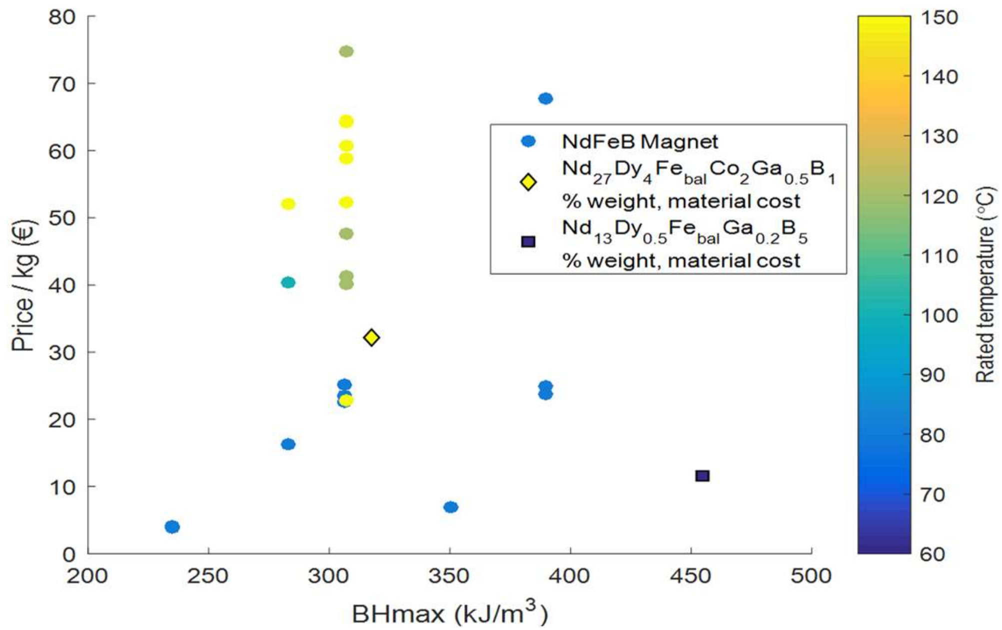
Electrical Machine Cost – Actual materials

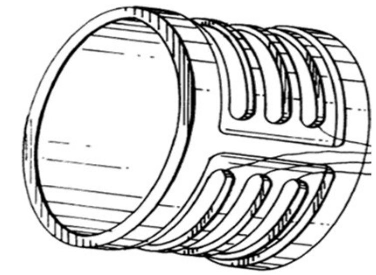


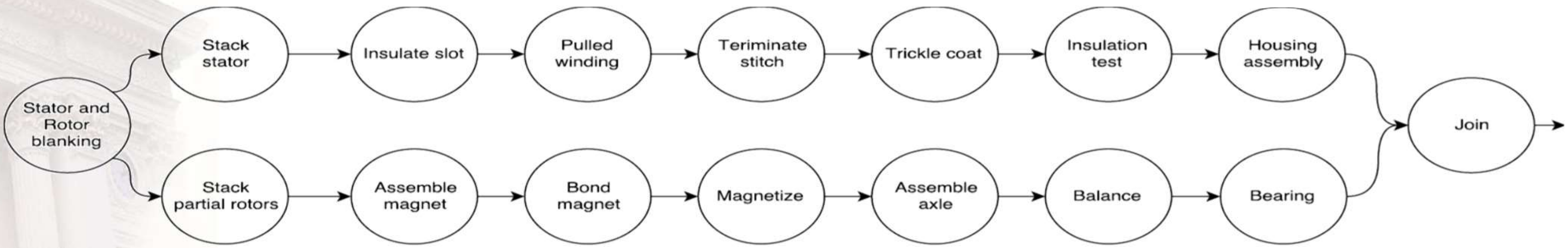
Electrical Machine Cost – Actual materials

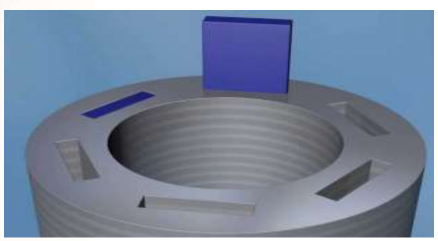


- Increased Nd with some Dy (Ga, Co) gives lower coercivity loss with increased temperature.
- Control of grain size important.
- Substitute elements (Dy, Ga, Co) increase price.

Electrical Machine Cost – Manufacturing







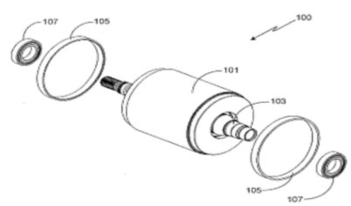
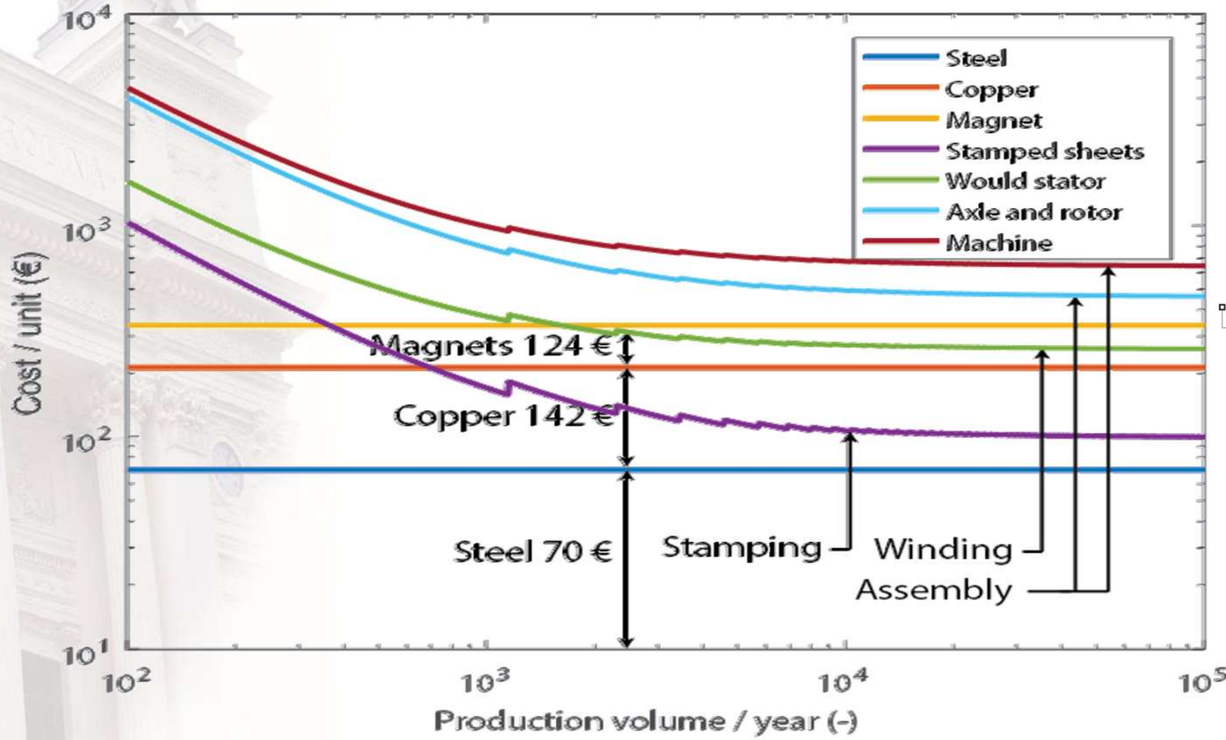
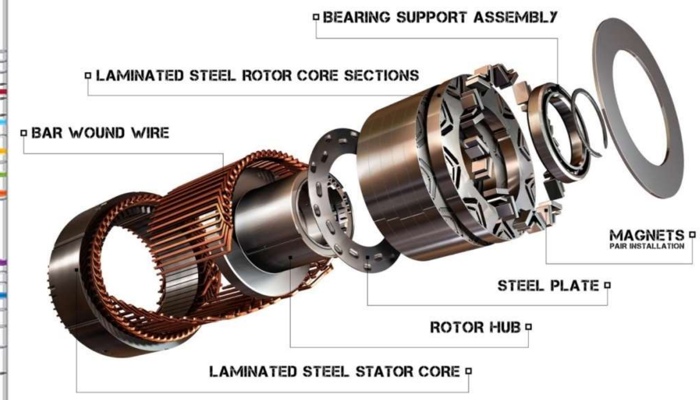


FIG. 1

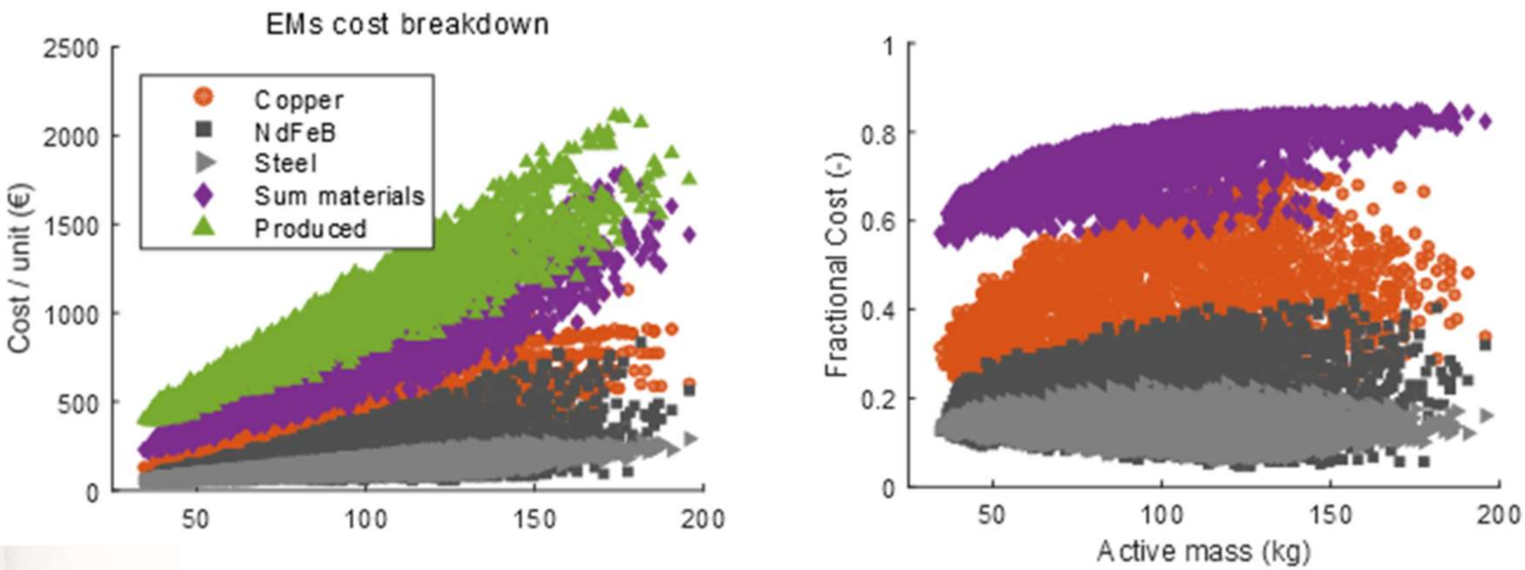
Electrical Machine Cost



Note log scale.



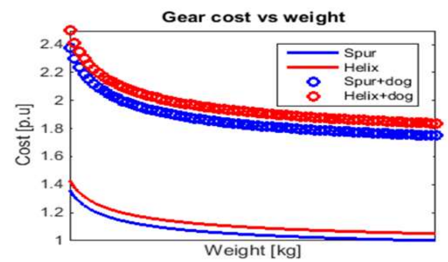
Electrical Machine: Cost



Transmissions

Preliminary Design → Housing & Shafts .... → Cost of each components → Gearbox cost and size

- Sizing each gear mesh following AGMA standards

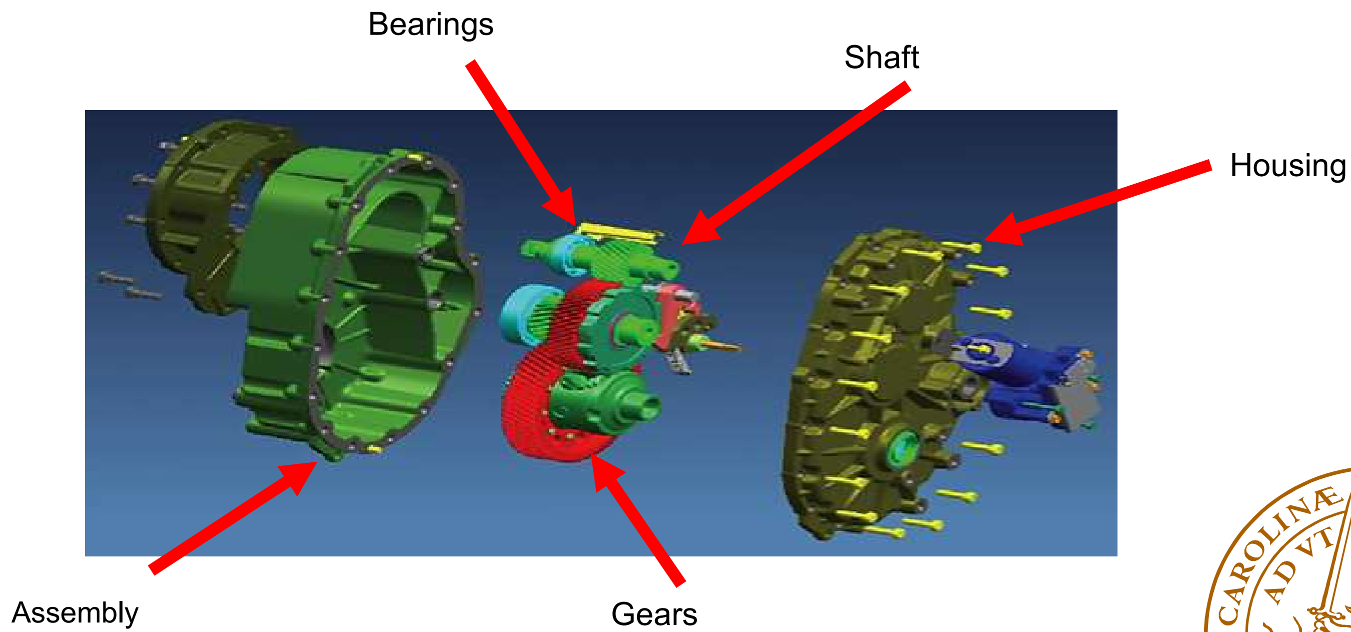


Transmissions

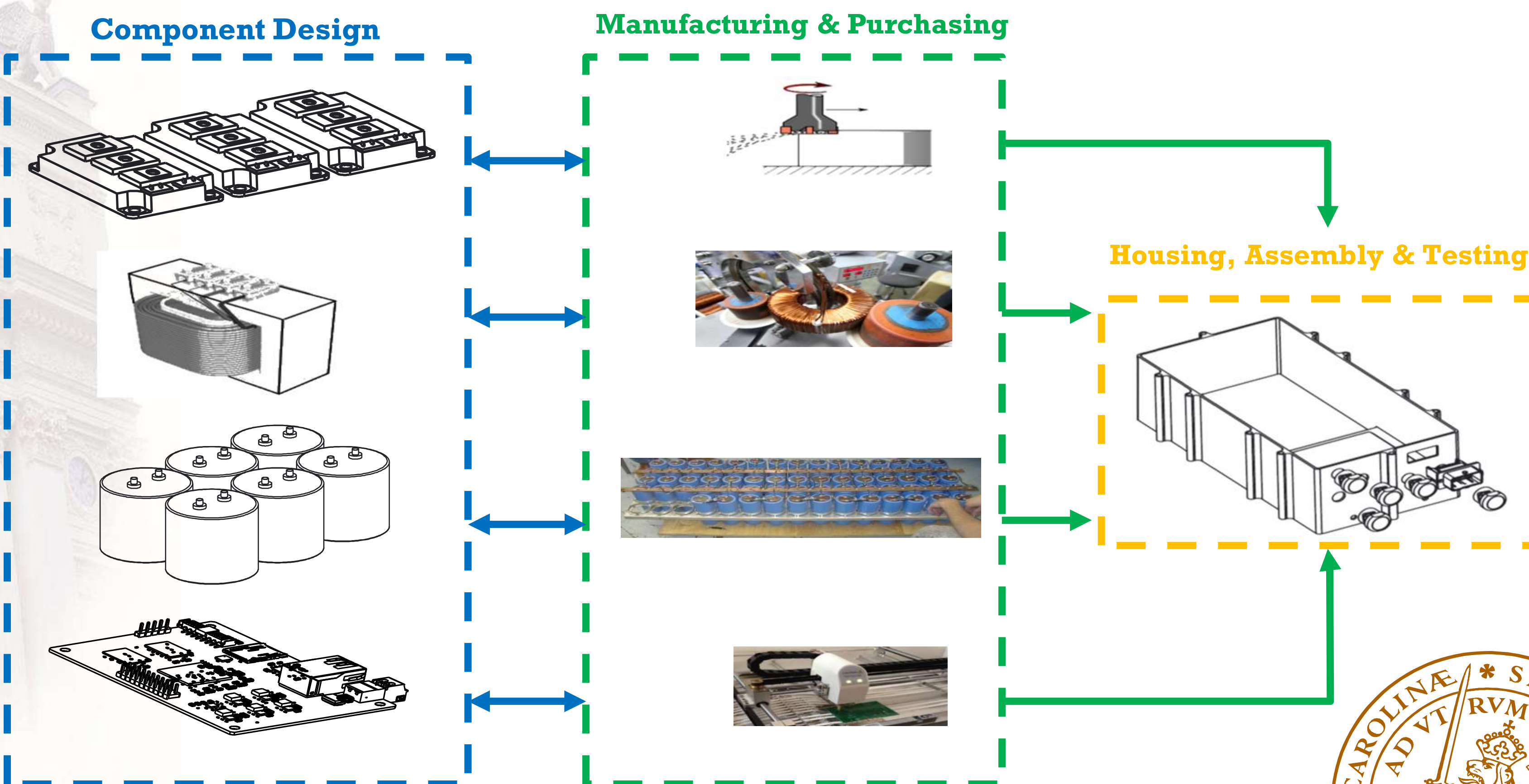
Preliminary Design → Housing & Shafts .... → Cost of each components → Gearbox cost and size

+

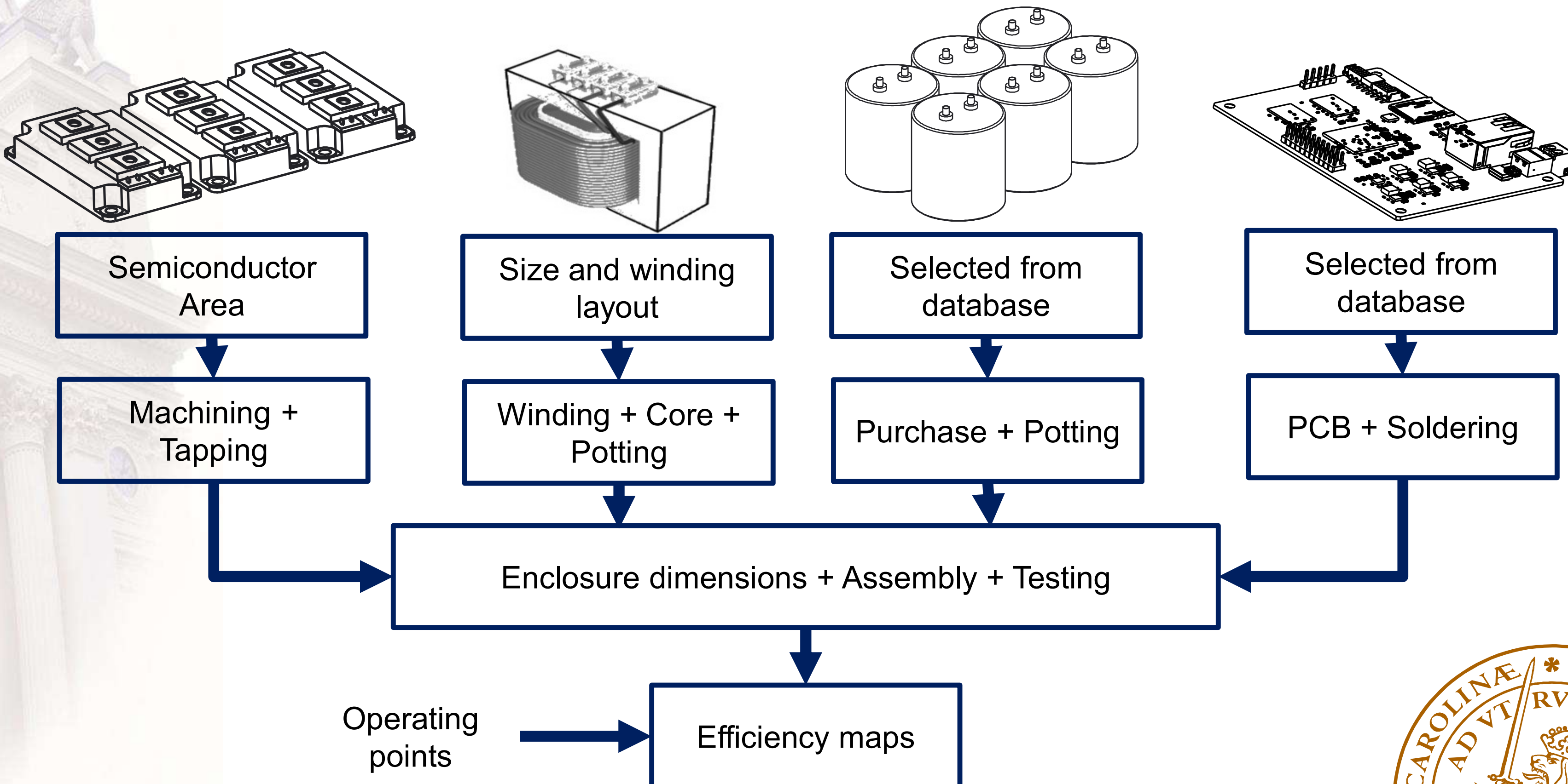
Fork
Dog clutch
Piston
Carrier



PEC

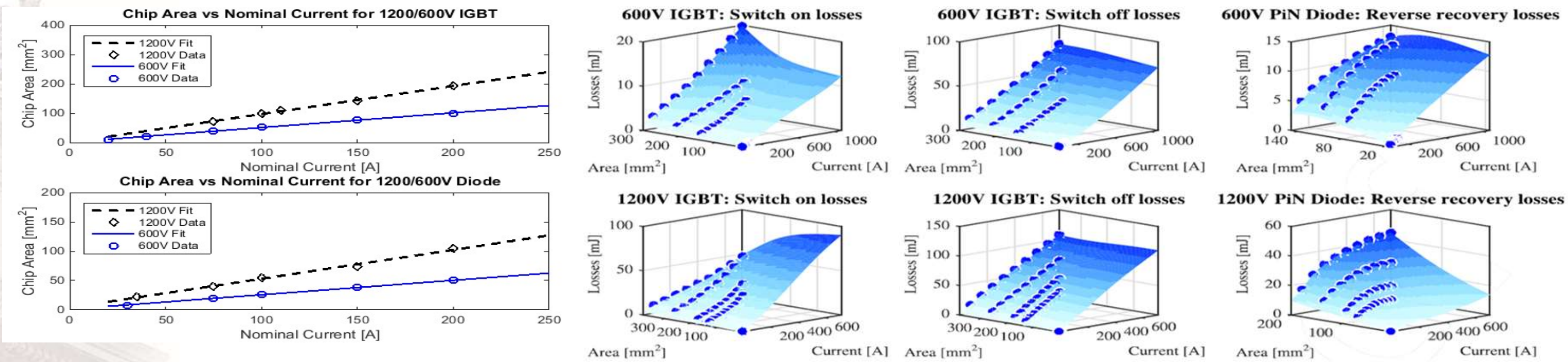

Component Design
Manufacturing & Purchasing
Housing, Assembly & Testing

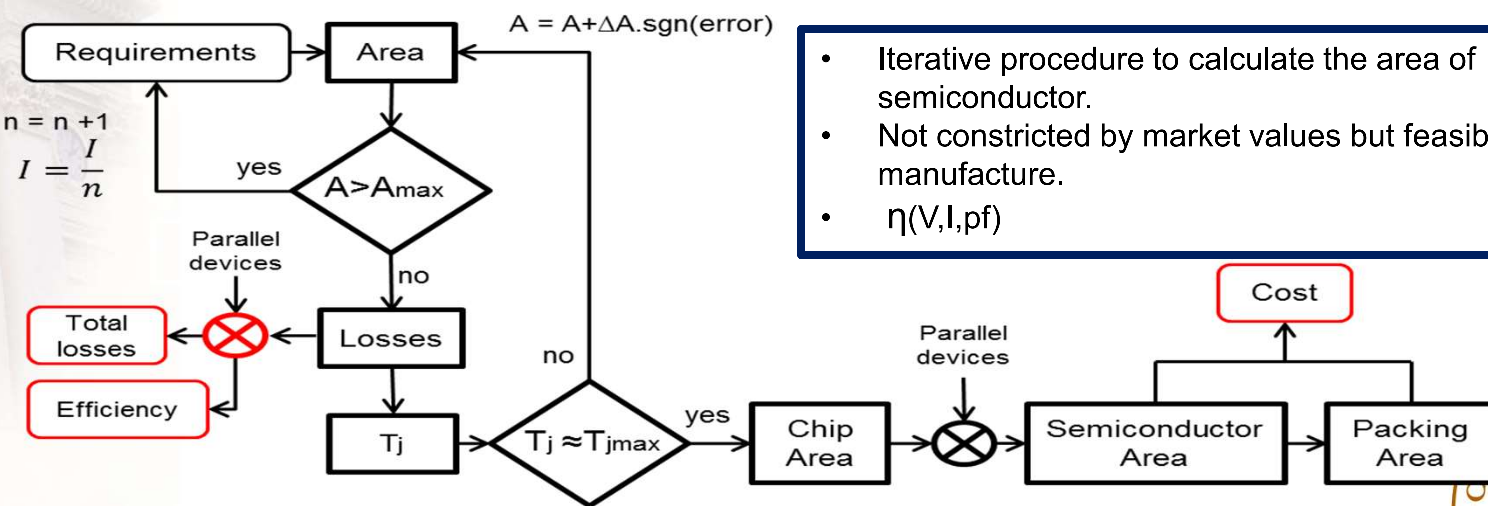
PEC



Semiconductor Area
Size and winding layout
Selected from database
Selected from database
Machining + Tapping
Winding + Core + Potting
Purchase + Potting
PCB + Soldering
Enclosure dimensions + Assembly + Testing
Operating points
Efficiency maps

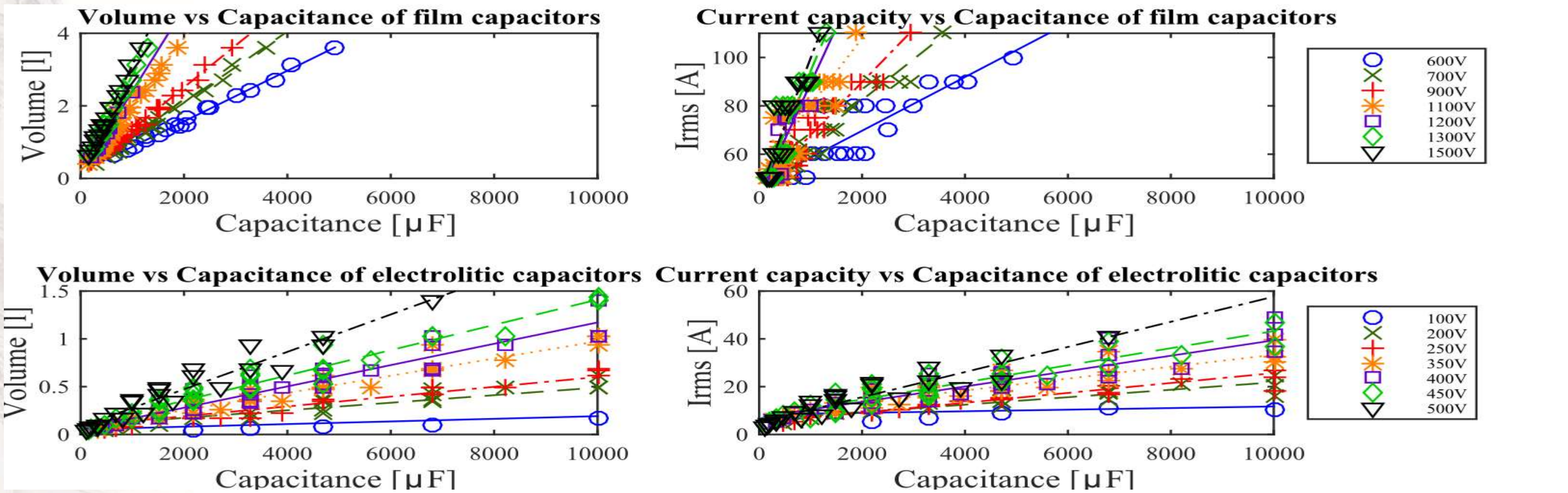
Power Electronics: Semiconductor devices



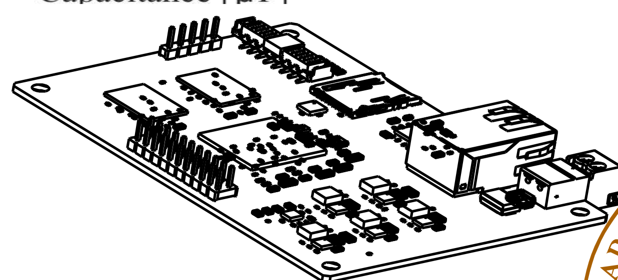


- Iterative procedure to calculate the area of semiconductor.
- Not constricted by market values but feasible to manufacture.
- η(V,I,pf)

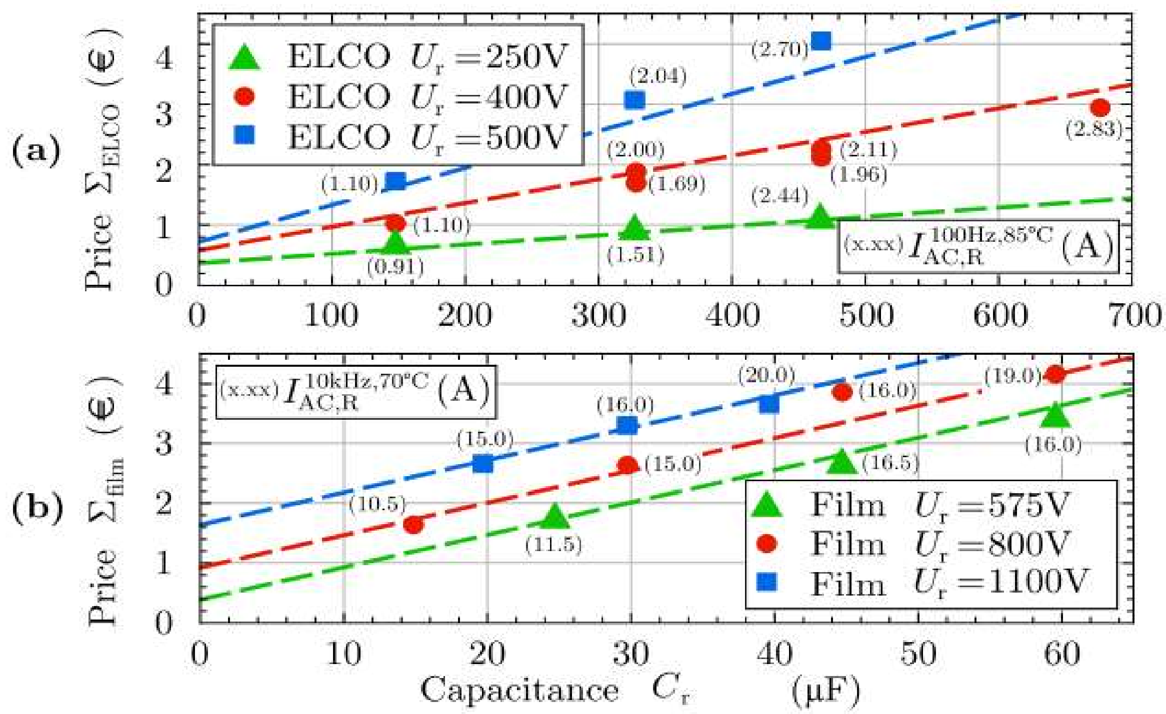
Power Electronics: DC-link Capacitors and Control unit



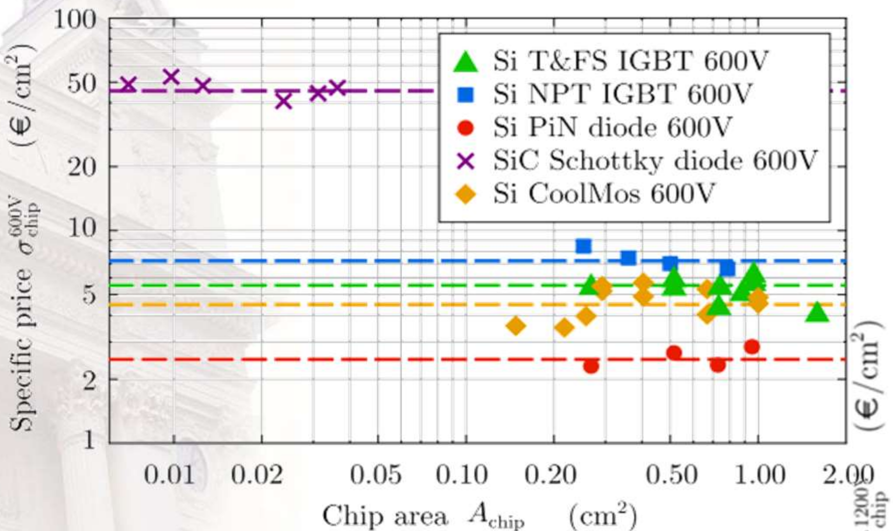
- μ–Controllers + transceivers (redundancy)
- Gate drivers and sensors
- Connectors and small electronics.
- PCB manufacturing + soldering.

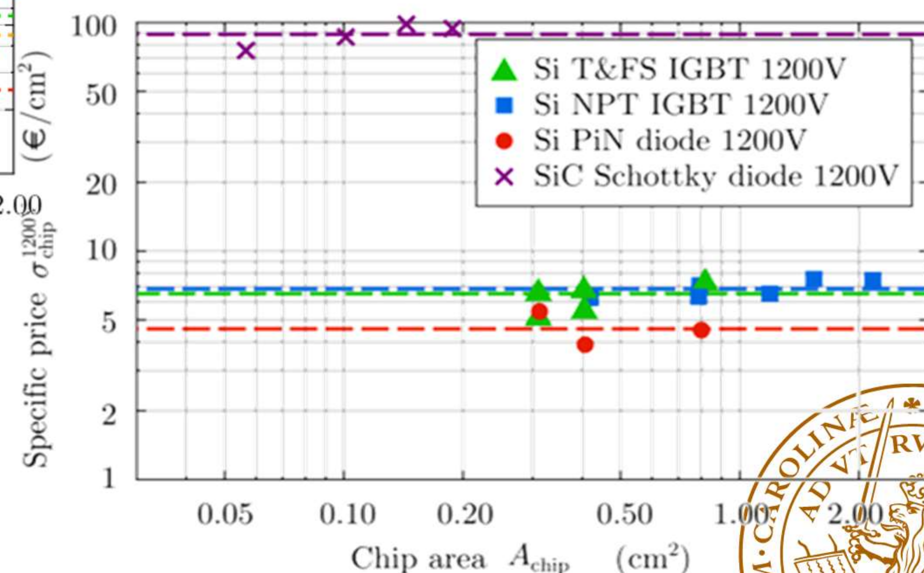


Power Electronics: ”Commodities”

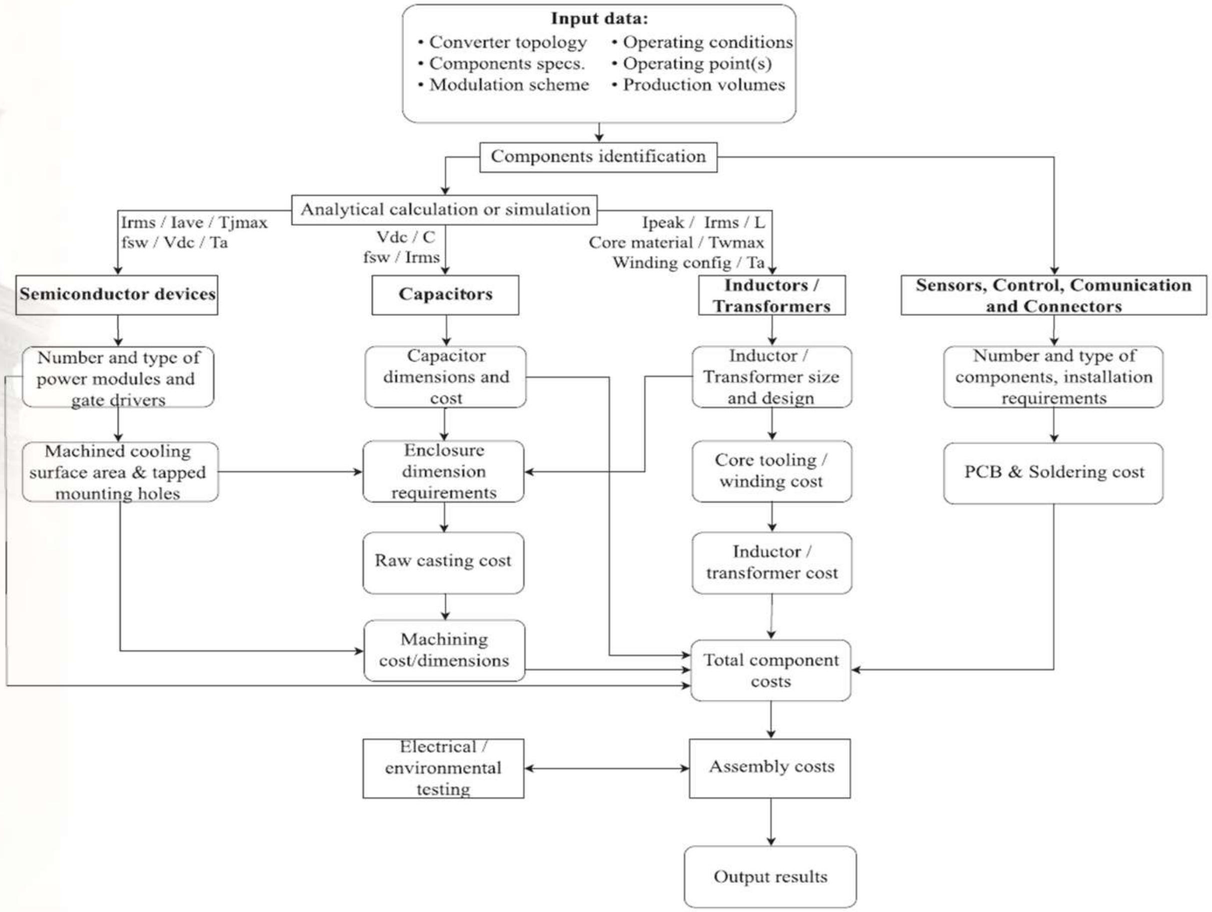


Power Electronics: ”Commodities”

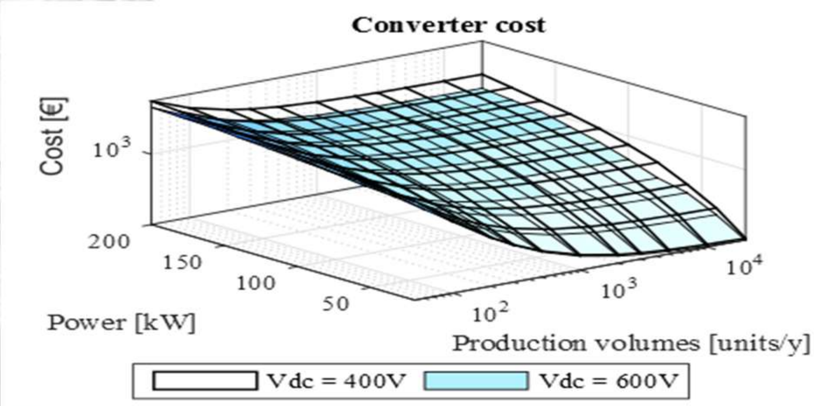




Power Electronics: Manufacturing



Power Electronics : Cost Examples



Cost per kW

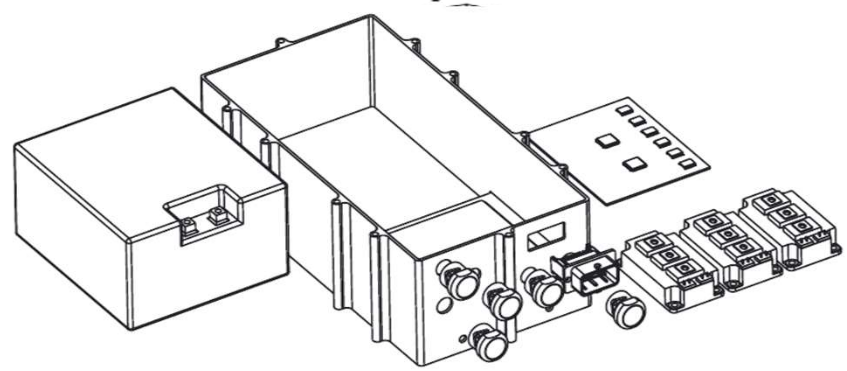


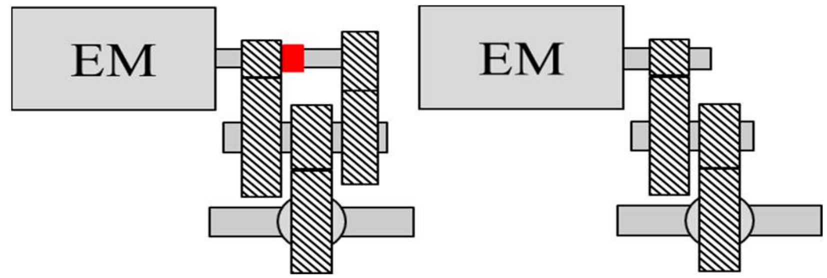
TABLE III: Cost of a 600V, Three phase, two level voltage source converter for EV/HEV application

Power-Units	100	1000	5000	10000	20000
20 kW	1085	358	294	286	282
40 kW	1160	434	369	361	357
60 kW	1231	504	439	431	427
80 kW	1315	588	523	515	511
100 kW	1397	670	605	597	593
120 kW	1422	695	630	622	618
140 kW	1510	783	718	710	706
160 kW	1588	862	797	789	785
180 kW	1633	906	841	833	829
200 kW	1747	1021	956	948	944

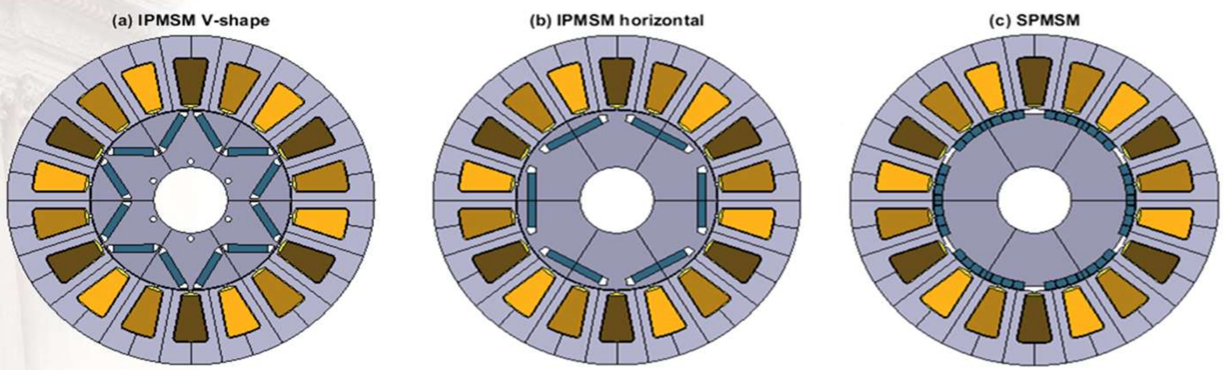
TABLE IV: Cost of a 400V, Three phase, two level voltage source converter for EV/HEV application

Power-Units	100	1000	5000	10000	20000
20 kW	1073	346	282	274	270
40 kW	1172	445	381	373	369
60 kW	1276	549	484	476	472
80 kW	1396	670	605	597	593
100 kW	1425	698	633	625	621
120 kW	1531	804	740	732	727
140 kW	1629	903	838	830	826
160 kW	1765	1038	973	965	961
180 kW	1780	1053	988	980	976
200 kW	1895	1168	1103	1095	1091

Electric vehicle specifications	
Vehicle weight	1600 kg
Top speed	150 km/h
Starting torque (wheel)	2200 Nm
Continuous Power	80 kW ($v > 43$ km/h)
DC-link Voltage	400V



EM topologies:



Other Constraints:
- Fsw = 10kHz
- Semiconductor tech: IGBT & Si PiN diodes

Optimization process ...

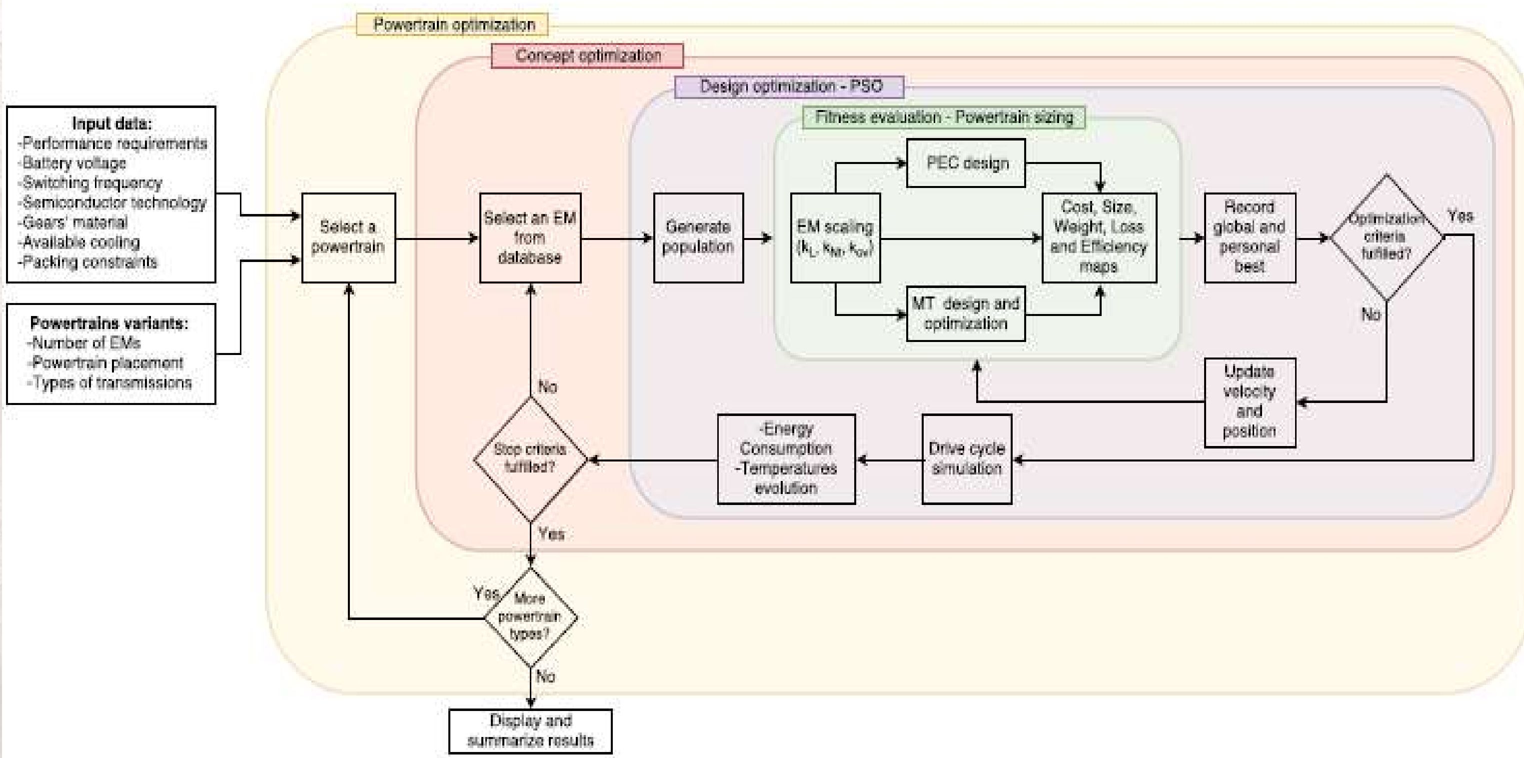
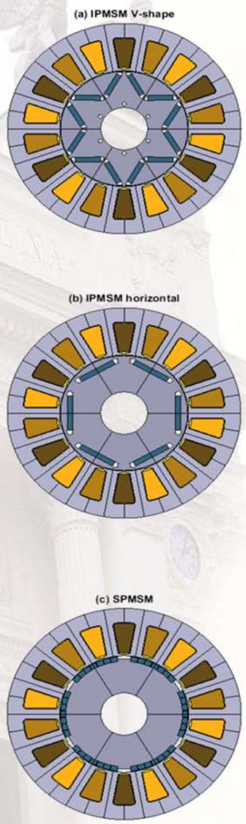
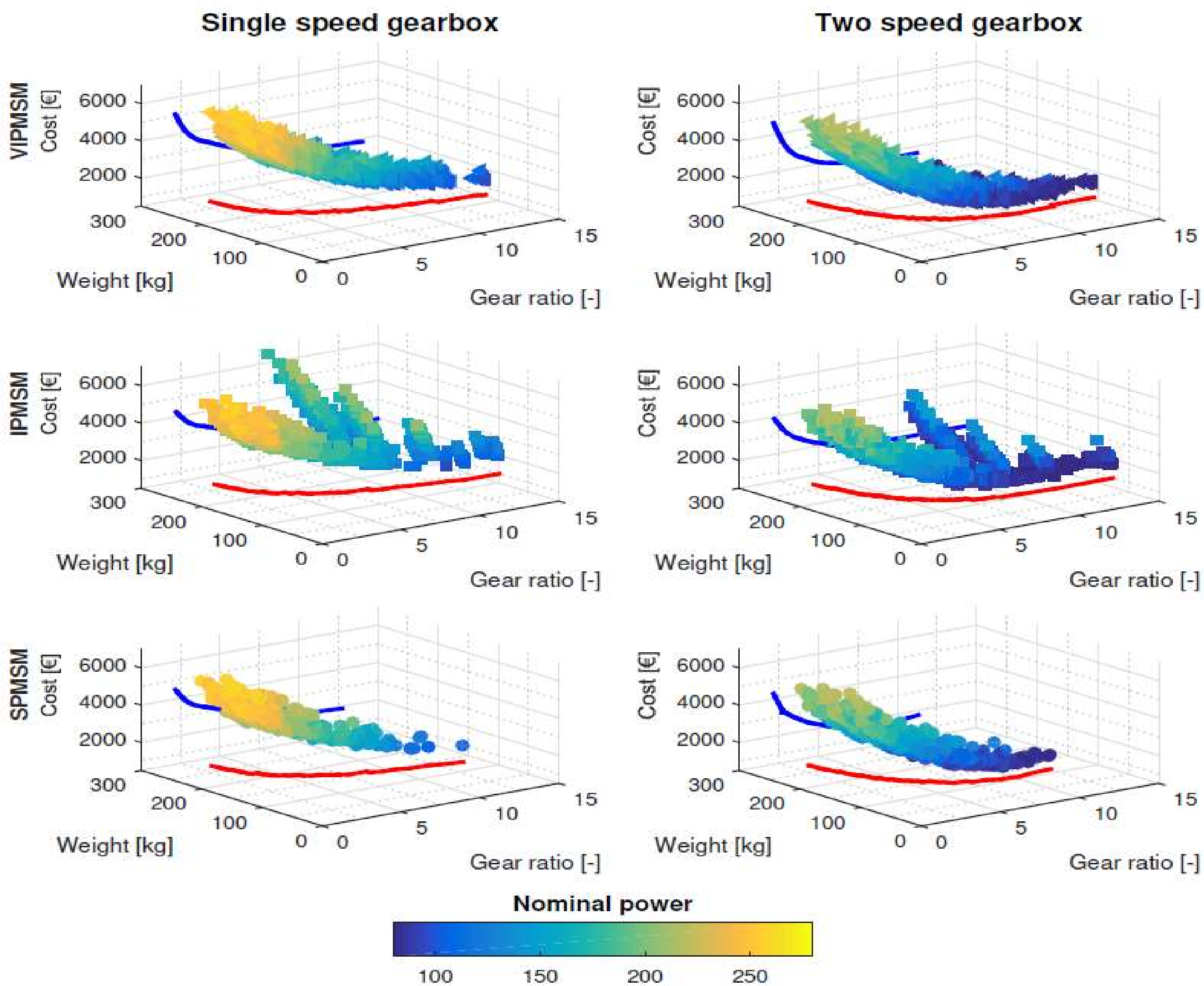


Figure 4.1: Powertrain optimization procedure.


(a) IPMSM V-shape
(b) IPMSM horizontal
(c) SPMSM


Single speed gearbox
Two speed gearbox
VIPMSM
IPMSM
SPMSM
Cost [€]
Weight [kg]
Gear ratio [-]
Nominal power
100
150
200
250

In another perspective ...

- 2 speed = lower cost
- Less demanding FWR

- To come:
  - SiC
  - HV (PD issues)
  - More machine types
  - Other transmissions
  - Other cooling concepts
  - ...
- Incremental improvement!
  - Like the ICE ...

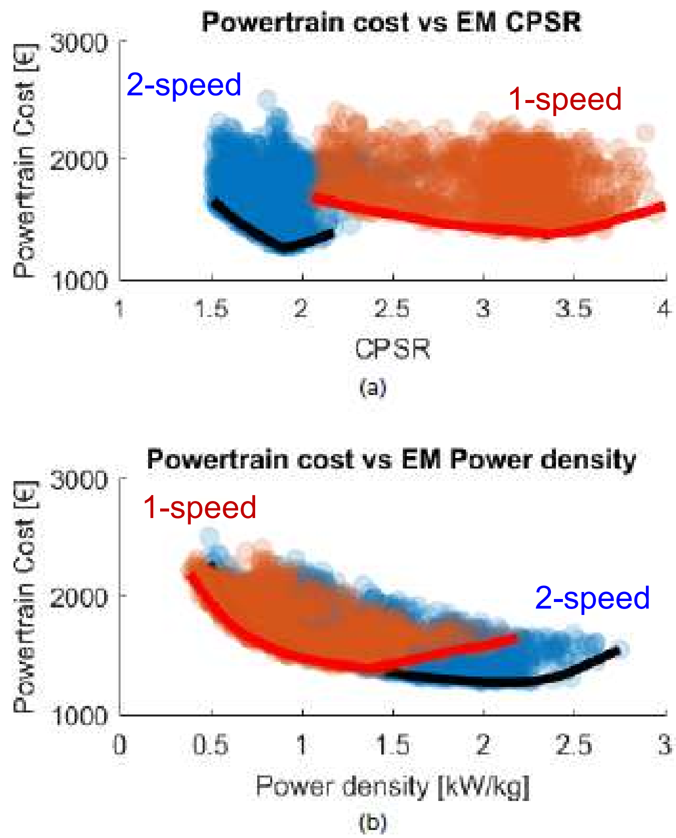


Figure 4.10: (a) Cost vs CPSR and (b) Cost vs Power density tradeoffs for all EM designs in the database when optimizing for cost. Two speed gearbox concepts are shown in blue while single speed transmissions are shown in red.