Green Energy and Charging of EVs

Delft University of Technology

P Bauer

June 23, 2015

Our Faculty

- The faculty consists of 5 departments:
  - Applied Mathematics
  - Electrical Sustainable Energy
  - Intelligent Systems
  - Microelectronics
  - Software and Computer Technology

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Our department

Electrical Sustainable Energy

Intelligent Electrical Power Grids

DC Systems, Energy conversion and Storage

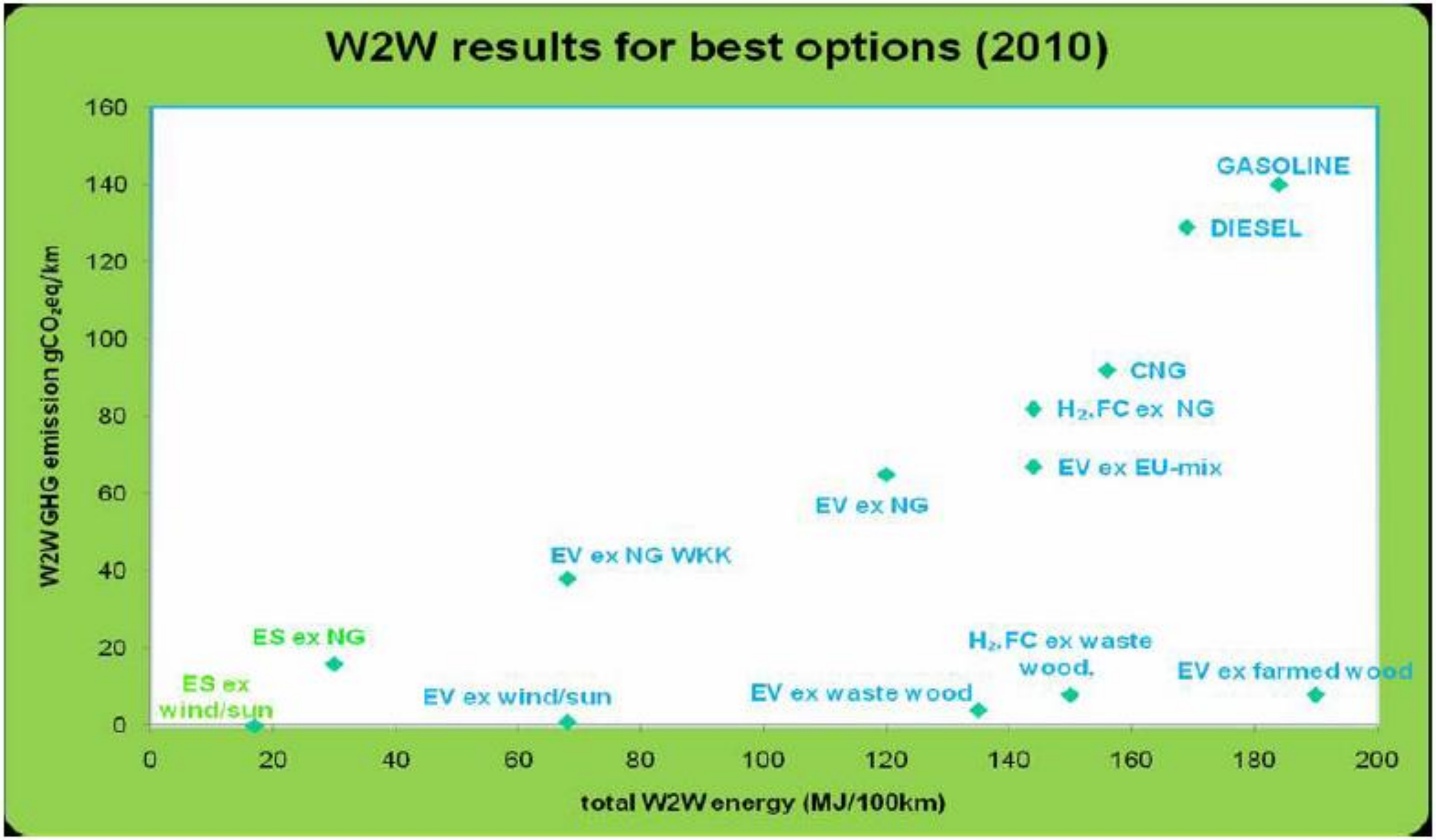
Photovoltaic Materials and Devices


ACME
GRAVEL
COMPANY
HEAVY METAL
PLUMBING
The WORLD WITHOUT ENGINEERS
Agilent Technologies
http://www.educatorscorner.com
Anvari.org

Current Challenges facing EVs

- Expensive means of transport - 25-50 % Batteries
- Limited Driving Range – Battery Technology
- Limited Charging points - Infrastructure
- Long Charging Times – Electric grid issues
- Other Challenges

Implication on CO_2emissions



Reflection

There is a future
and talking about this future is the only way to shape it

Alan Kay said in 1971:
The best way to predict the future is to invent it

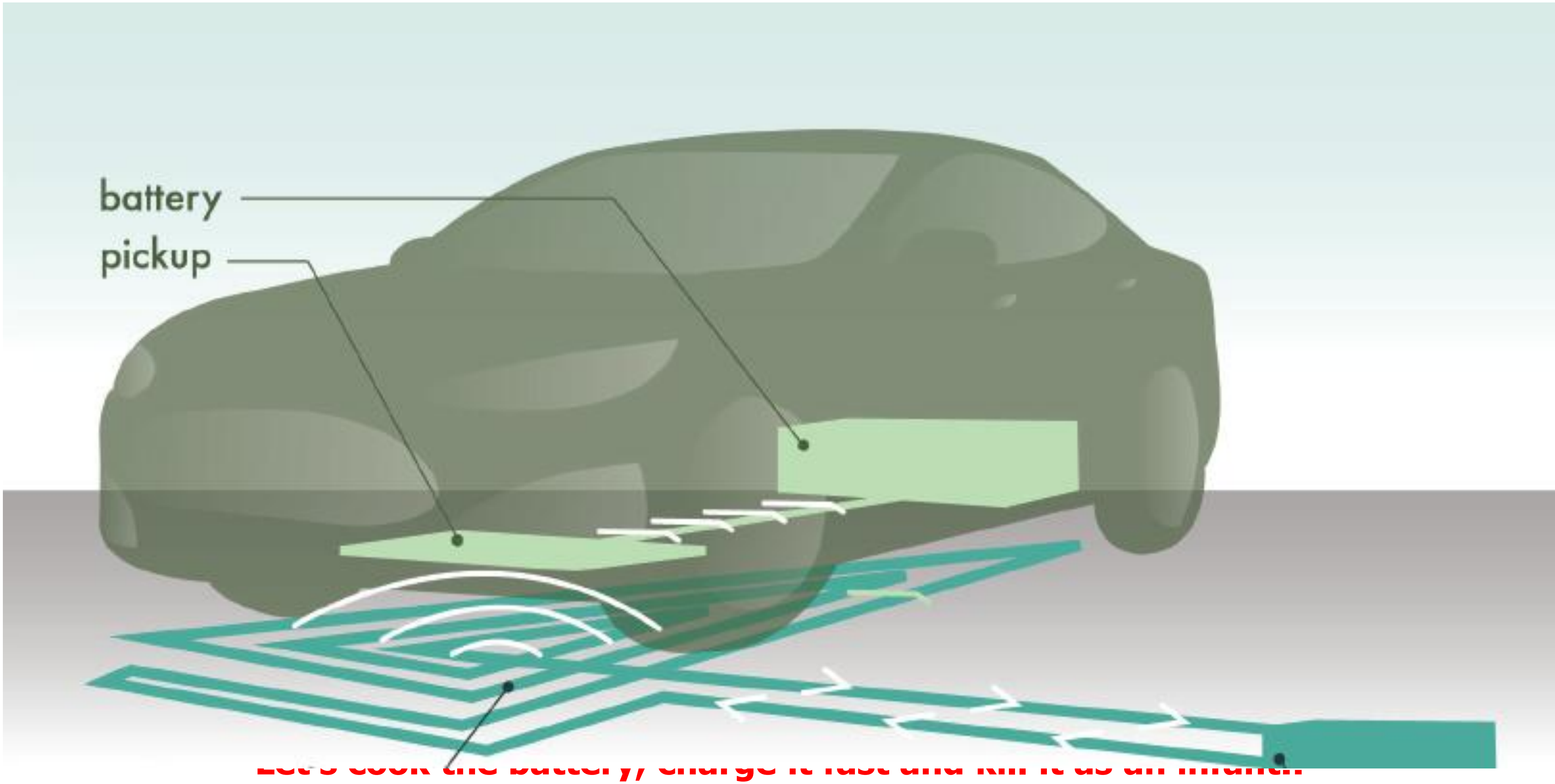
http://www.smalltalk.org/alankay.html

Let us invent the future

- Roads powering electrical vehicles
- Self healing roads
- Roads generating sustainable energy
- Roads allowing automated driving

With Power Electronics!

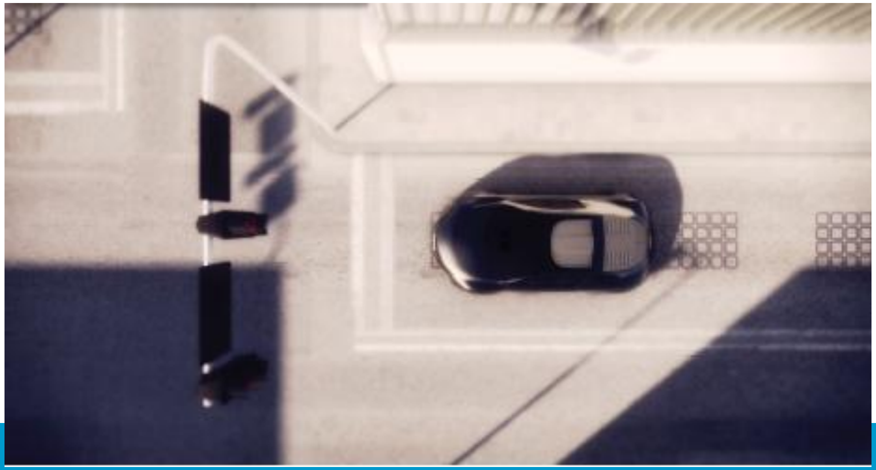
Roads powering electrical vehicles ?



Roads powering electrical vehicles

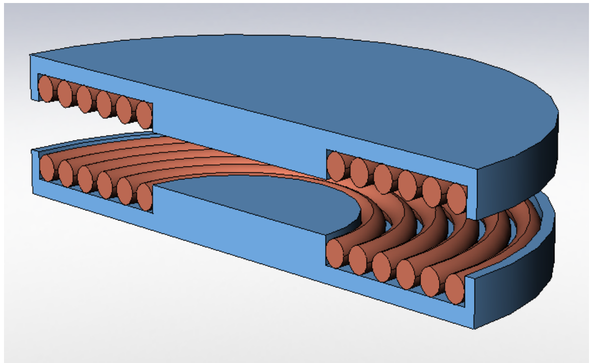
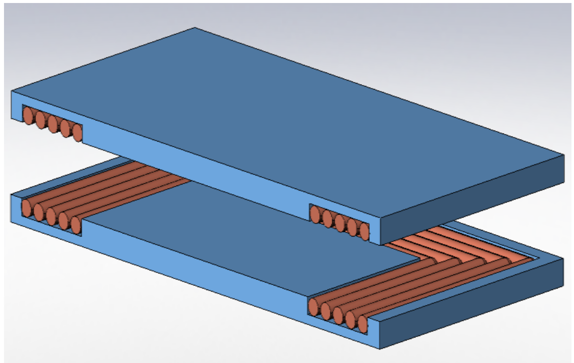
- Stationary Charging / Charging while parking

- Dynamic Charging / Powering while driving

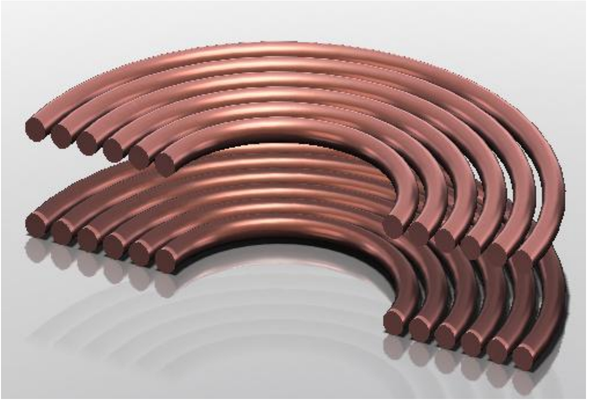
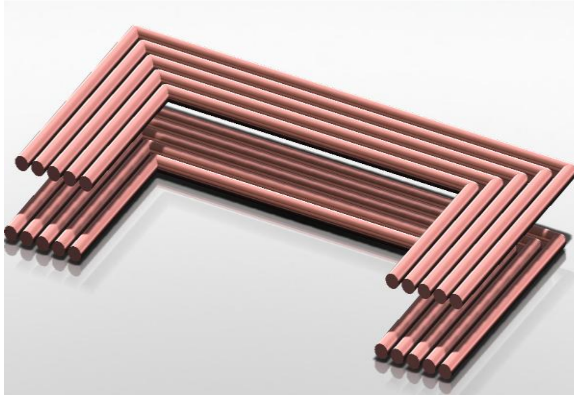


CPT Transformer
Configurations

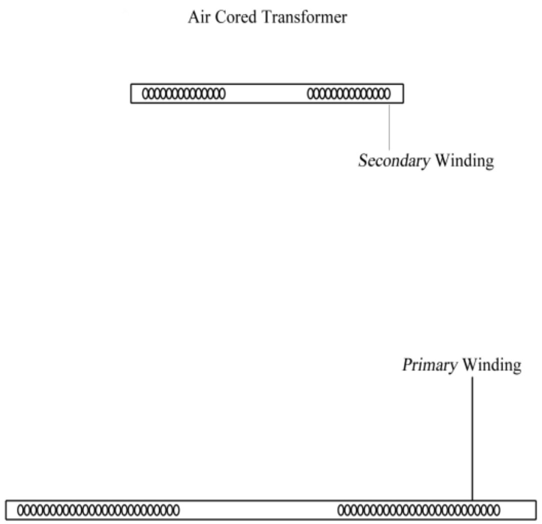
Magnetic Core

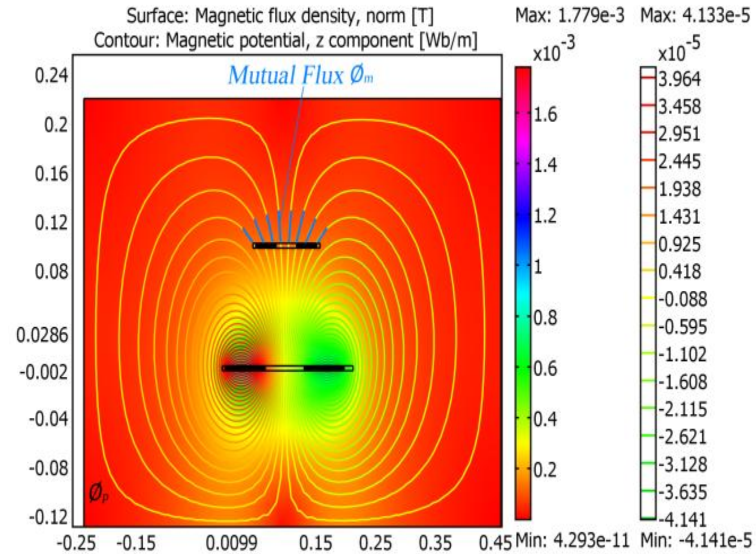



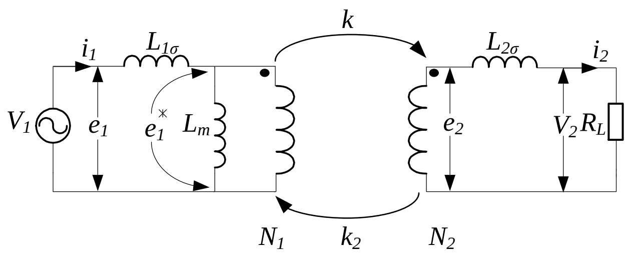
Air Core

CPT Transformer

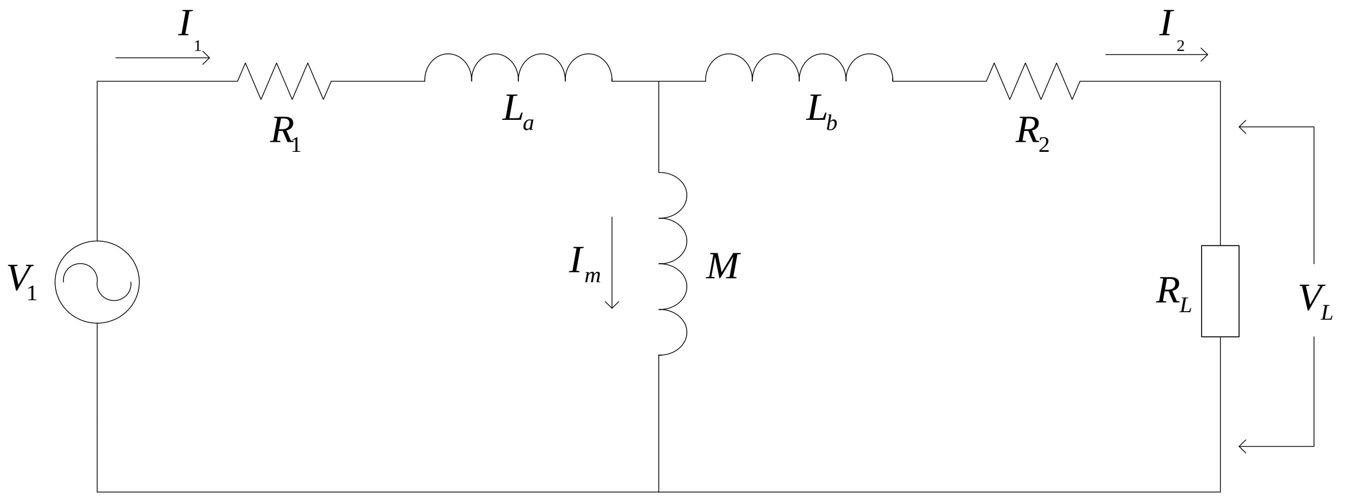






$$\frac{e_1}{e_2} = \frac{N_1}{N_2}\frac{d\emptyset_m/k_1}{d\emptyset_m/k_2} = \frac{N_1}{N_2}\frac{k_2}{k_1}$$

Equivalent CPT air core transformer model



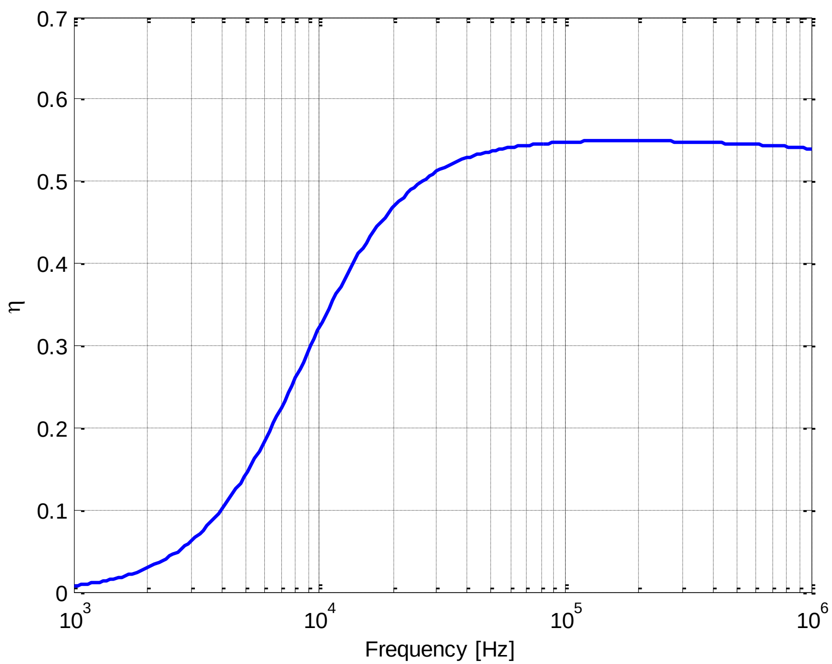
$$\eta = \frac{\left|\overline{I}_2\right|^2 R_L}{\left|\overline{I}_2\right|^2 R_L + \left|\overline{I}_2\right|^2 R_2 + \left|\overline{I}_1\right|^2 R_1}$$

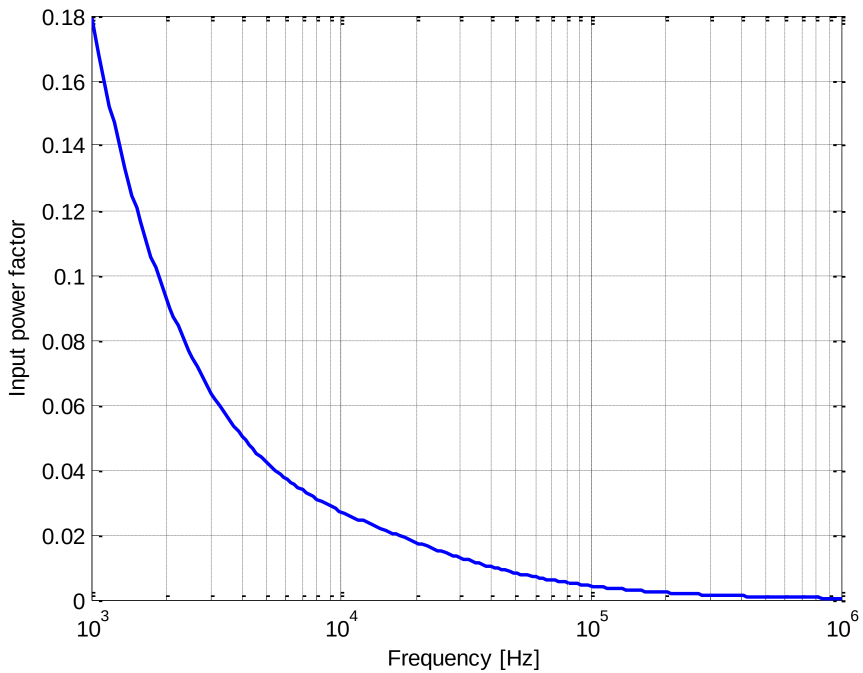
$$pf = \cos\left(\tan^{-1}\left[\frac{\mathrm{Im}(\overline{V}_1 \overline{I}_1^{\,*})}{\mathrm{Re}(\overline{V}_1 \overline{I}_1^{\,*})}\right]\right)$$

$$\eta_{\max} = \frac{R_L}{R_L + R_2 + R_1\left(\frac{L_b + M}{M}\right)^2}$$

Self inductance of primary winding L_1 [H]	112×10^{-6}
Self inductance of secondary winding L_2 [H]	15.8×10^{-6}
Mutual inductance M [H]	5.7×10^{-6}

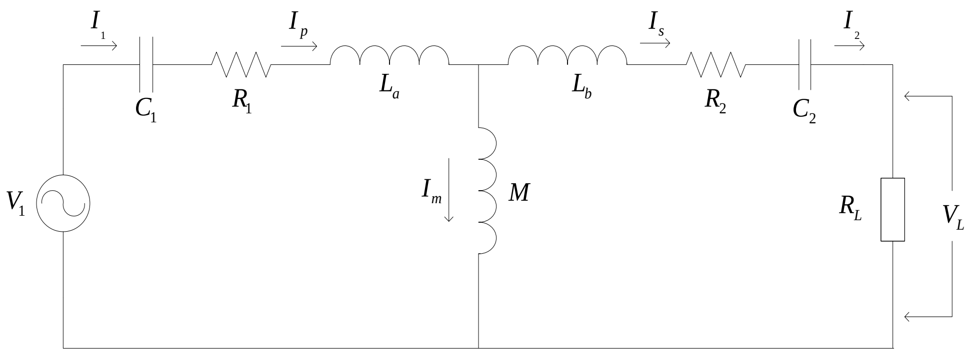
Power transfer capability

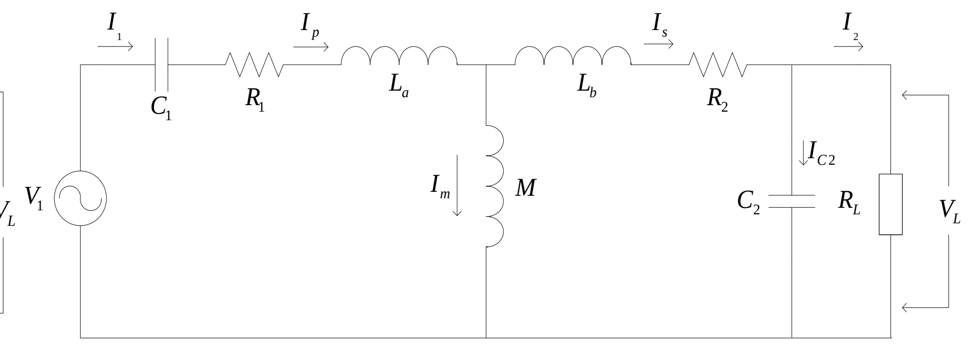




- Power transfer capability of the CPT system is rather poor
- Input power factor is low which implies large VA rating of the source

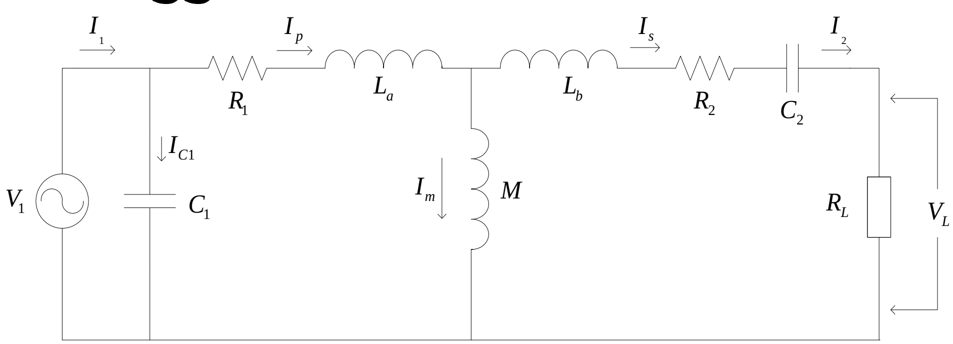
Compensation

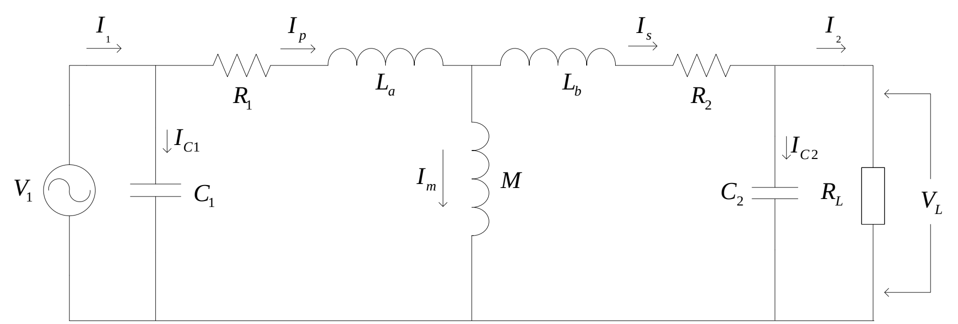




SS

SP

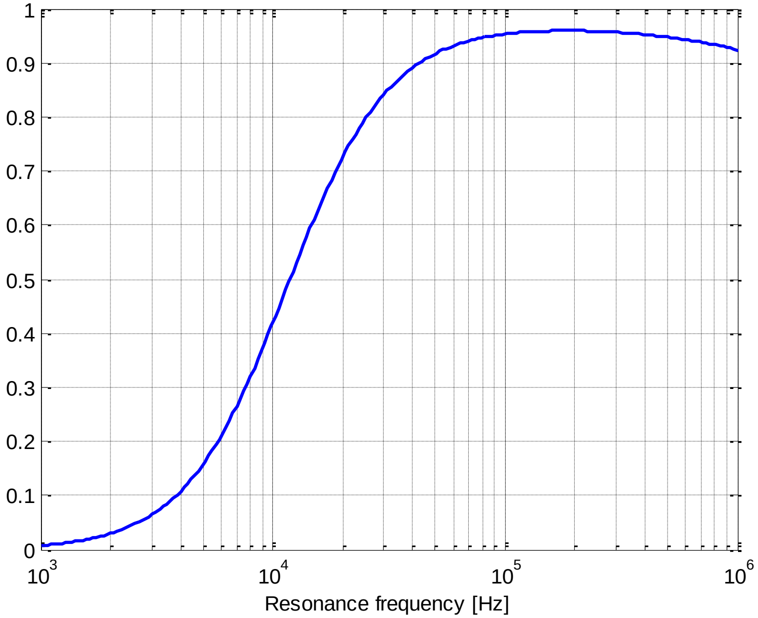




PS

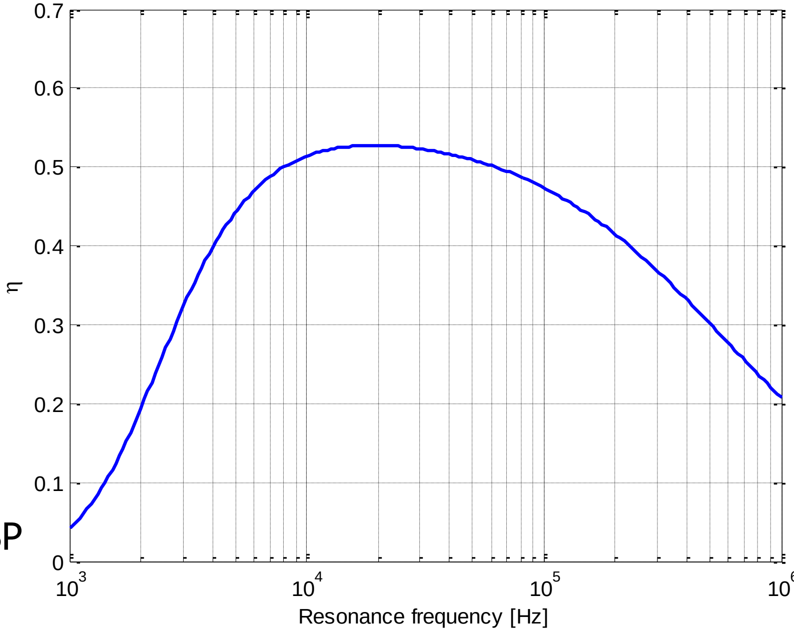
PP

SS



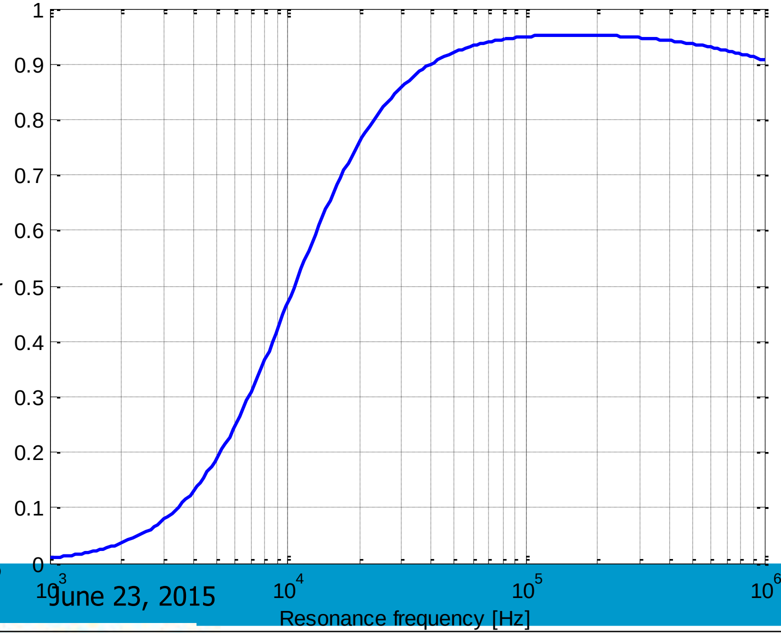
η
Resonance frequency [Hz]

SP



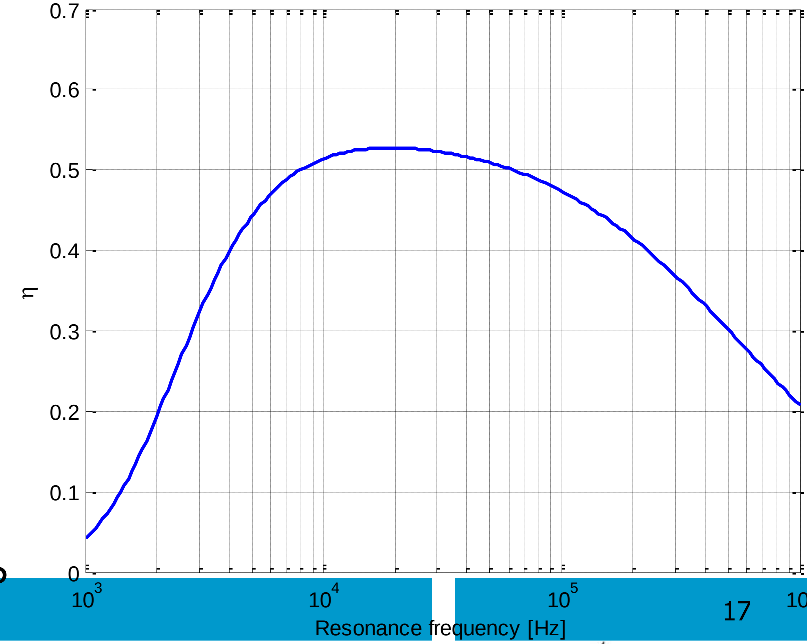
η
Resonance frequency [Hz]

PS



η
Resonance frequency [Hz]

PP



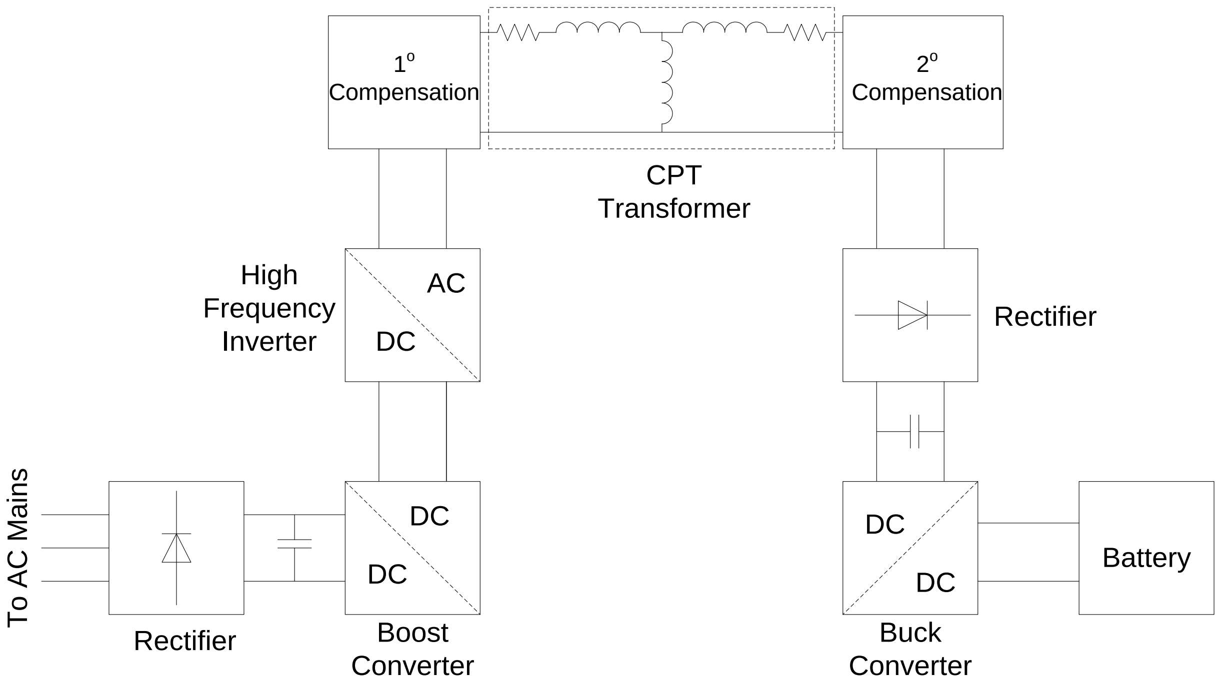
η
Resonance frequency [Hz]

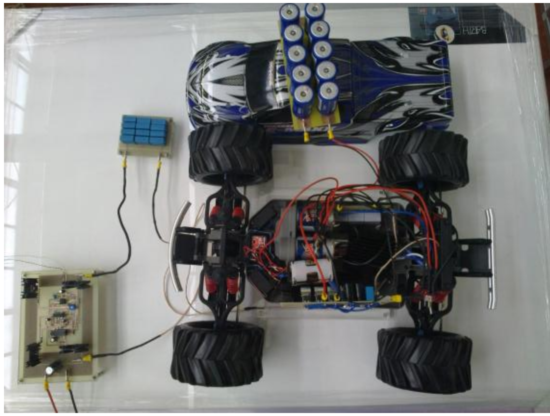
Losses in CPT transformer

- Iron losses (eddy current and hysteresis losses)
  - Present only in case of transformer with magnetic core

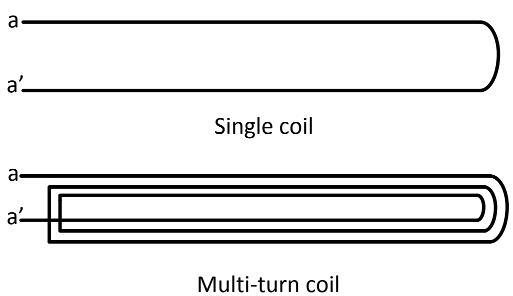
- Copper losses (I^2R losses)
  - Frequency dependent behavior of resistance of the windings
  - Non-uniform distribution of current density in conductors at high frequencies
  - Eddy current effects: Skin effect and Proximity effect

System Configuration

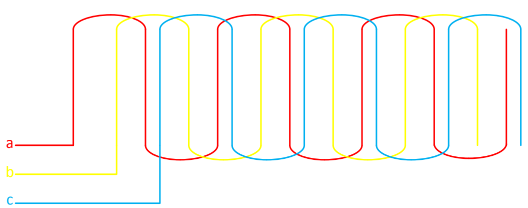




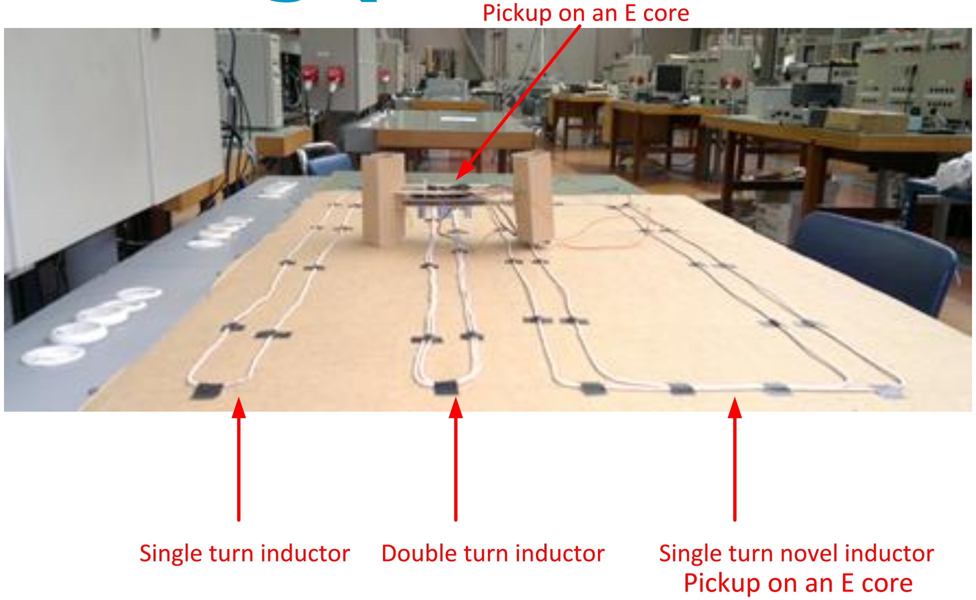
Charging while driving (On-road charging)

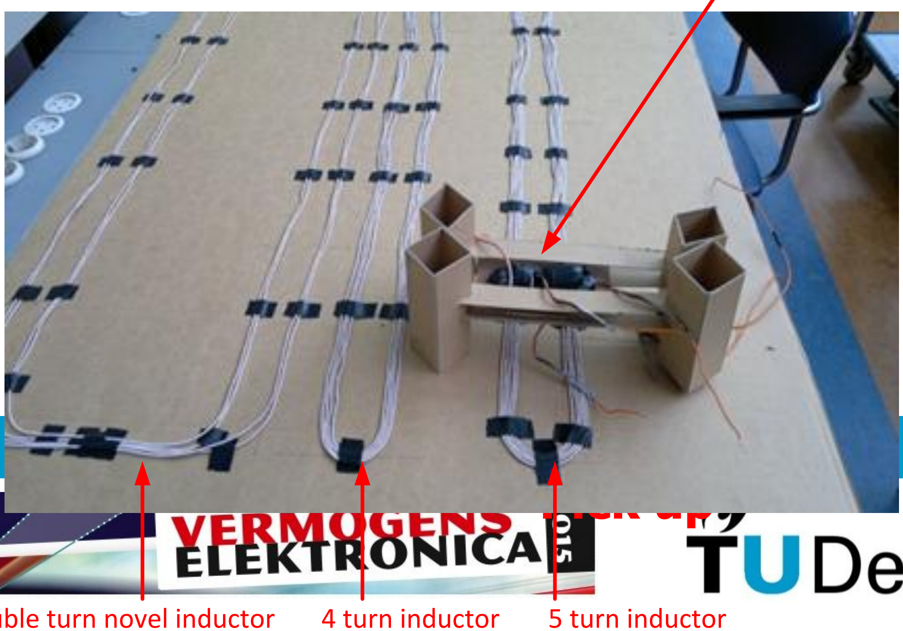


Coil configuration and definition of single and multi-turn coils



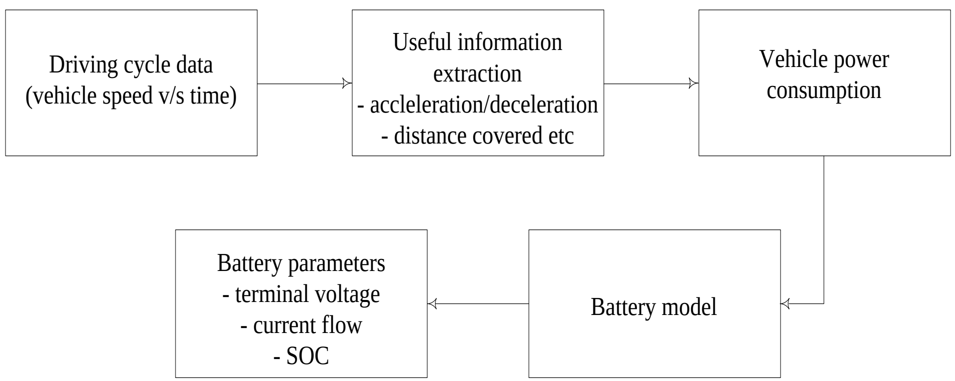
- Sinusoidally distributed three phase windings





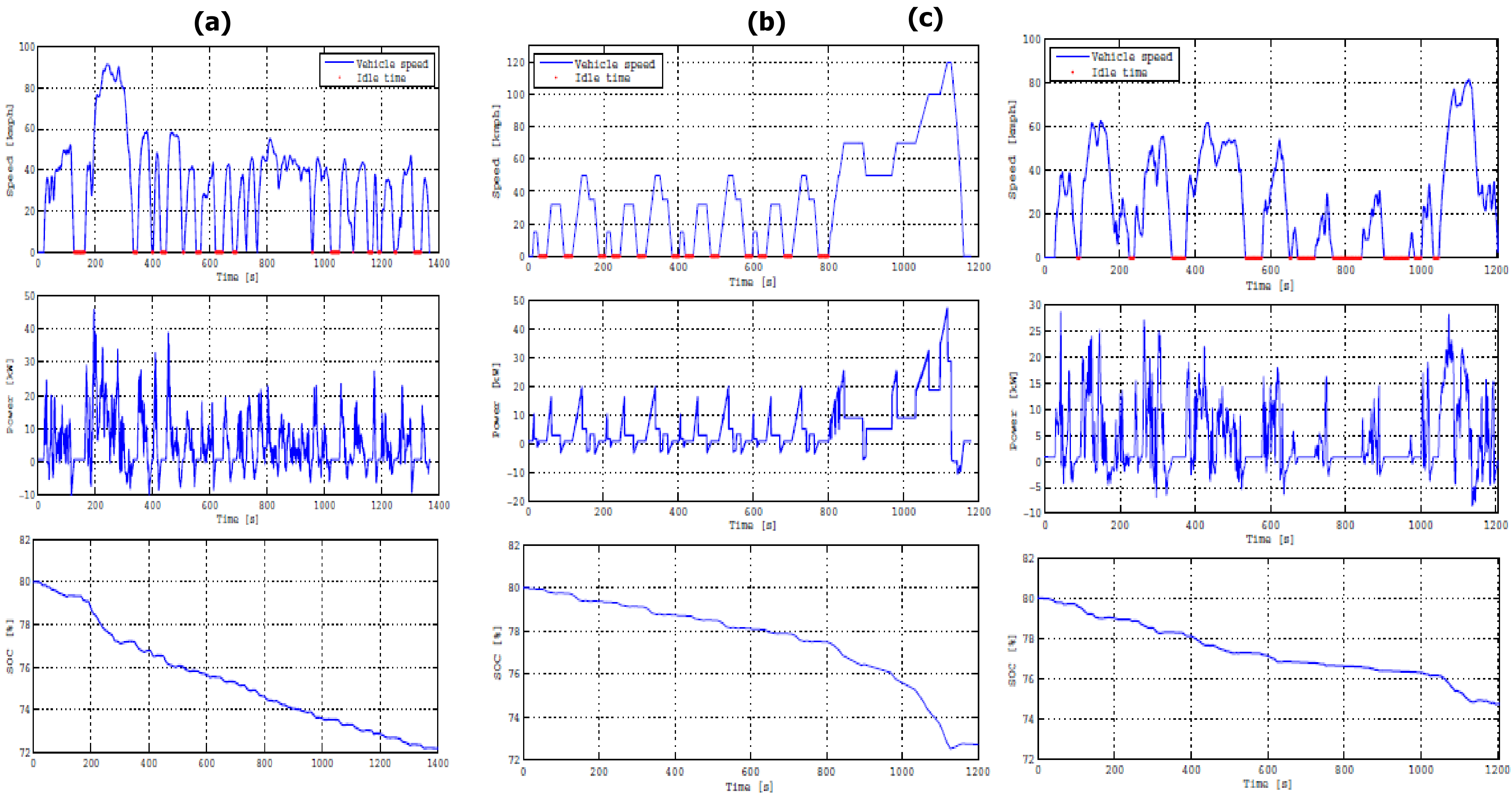
Power for on road charging

- **Case study A (Charging at the traffic signals)**
  - **U.S. standard FTP 72 (Federal Test Procedure) cycle also called Urban Dynamometer Driving Schedule (UDDS).**
  - **European standard ECE-EUDC combined urban test cycle.**
  - **Japanese standard JC08 urban test cycle.**
- **Case study B (Charging while driving in highways)**
  - **HighWay Fuel Economic Test (HWFET) cycle considered back to ba**
  - **Mountain Energy Expensive Driving Cycle (MEEDC)**



Procedure for battery parameter calculation

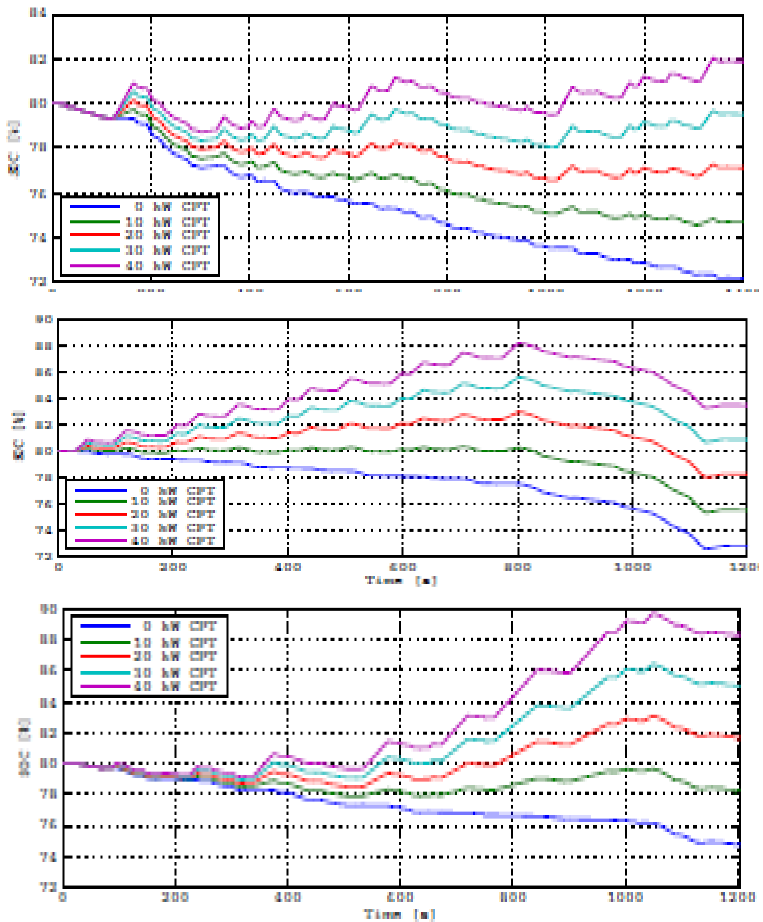
Case study A – Charging at traffic signals



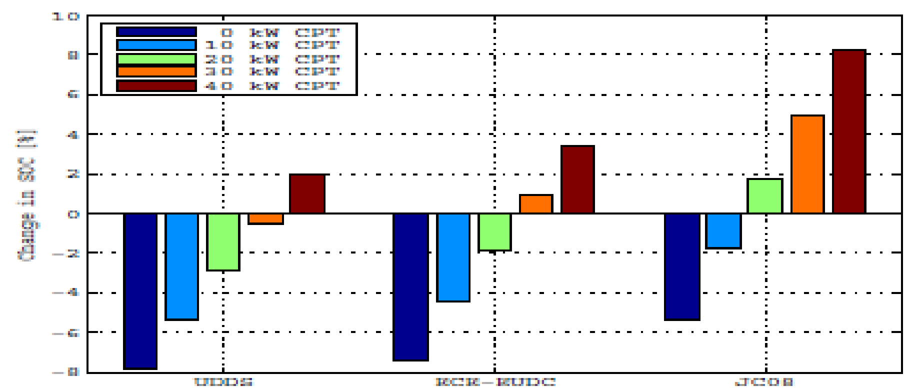
Vehicle speed, battery power flow and SOC of battery for (a) UDDS and (b) ECE-EUDC driving cycles (c)

Case study A – Charging at traffic signals

(a)



(b)



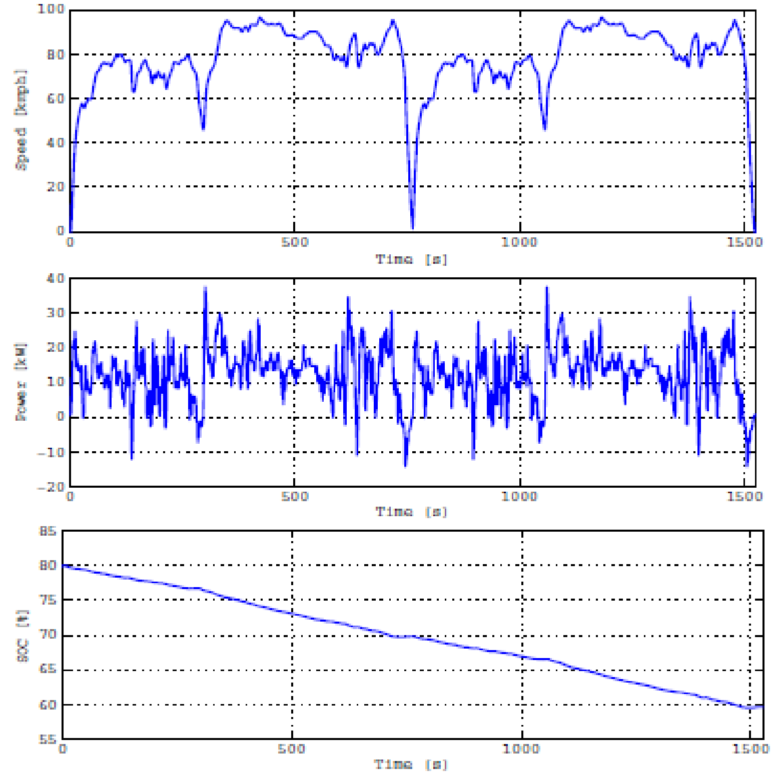
OC of battery for different driving cycles (b) change in SOC

Case study B – Charging while driving

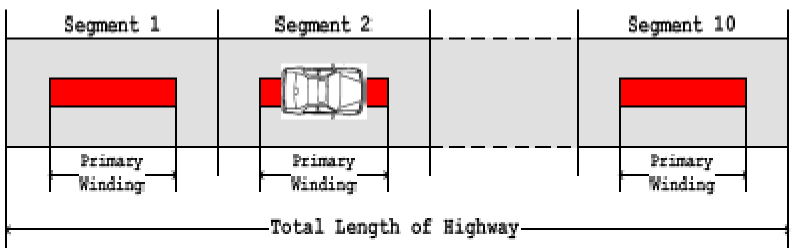
(a)

Duration (s)	Distance travelled (km)	Average speed (kmph)	Maximum speed (kmph)
1526	32.9	77	96.4

(b)`,m

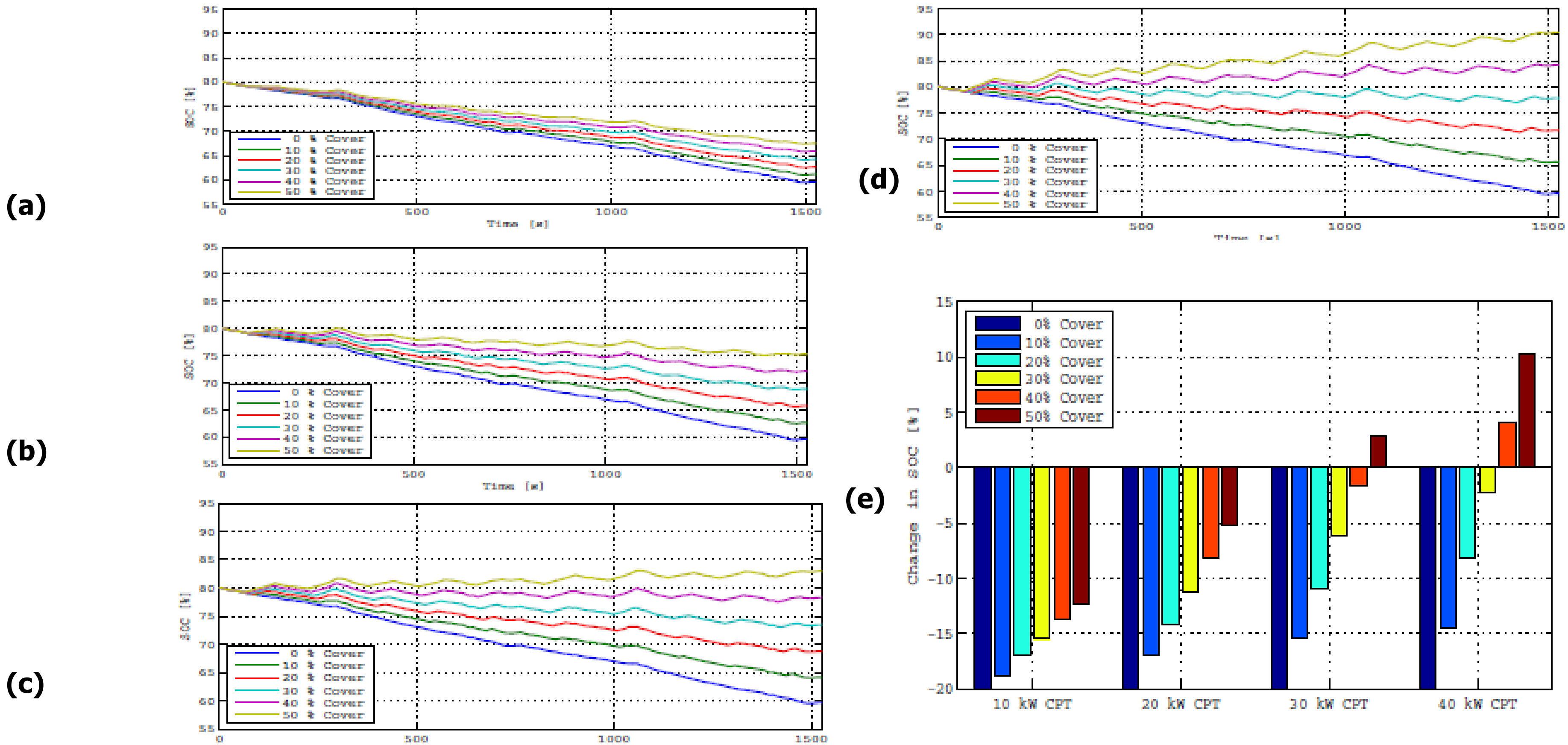


(c)



aracteristics of HWFET 2 (b)Vehicle speed, battery power flow and SOC for HWFET2 (b) Primary winding age

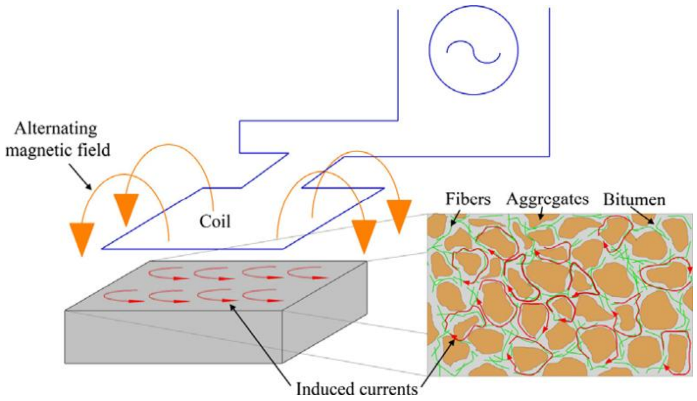
Case study B – Charging while driving

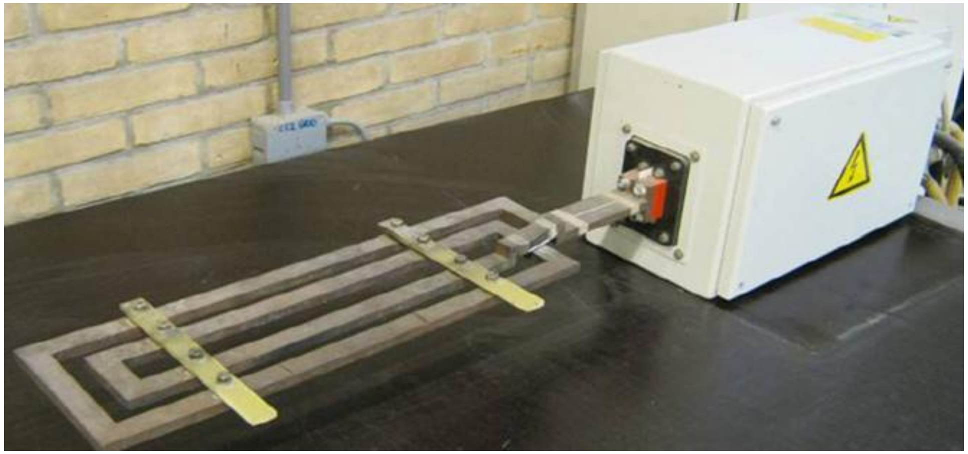


SOC of battery for (a) 10kW, (b) 20kW, (c) 30kW, (d) 40kW CPT and (e) Change in SOC for the entire duration of HWFET2

Self healing roads

- Induction heating of mastic asphalt for crack control
- Self healing of cracks is temperature dependent
- conductive additives (type 00 steel wool, steel fiber and steel slag)





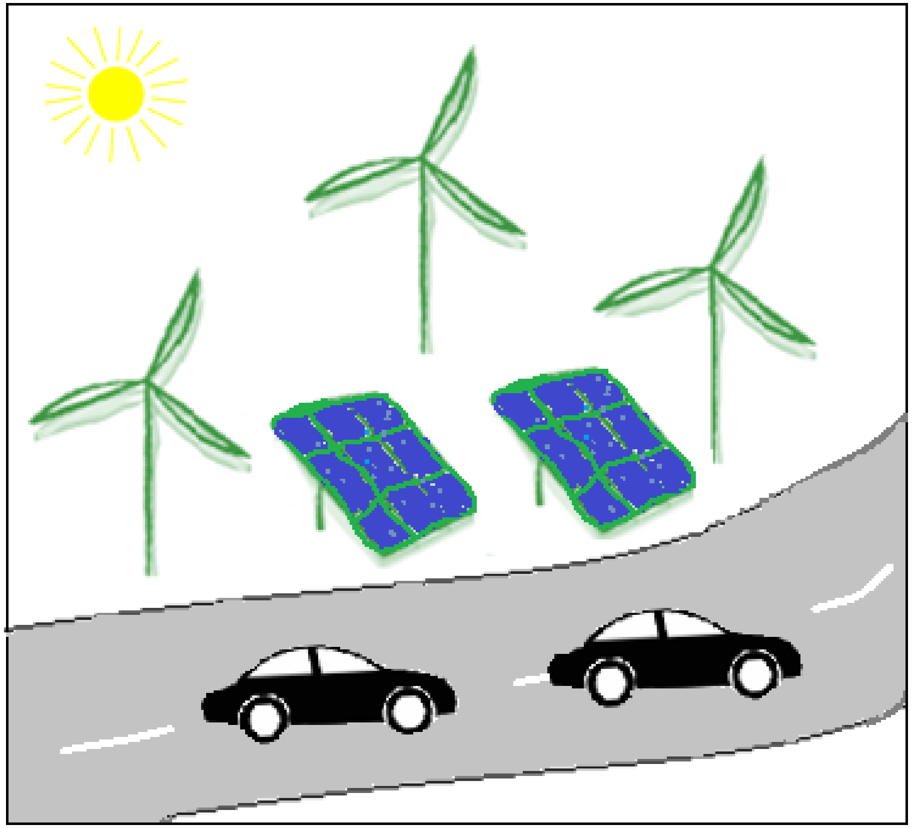
Erik Schlangen TU Delft

Roads generating sustainable energy

- Solar roads

- Mark Bolech. Stan Klerks, TNO

Power electric vehicles while driving from Wind & Solar Energy

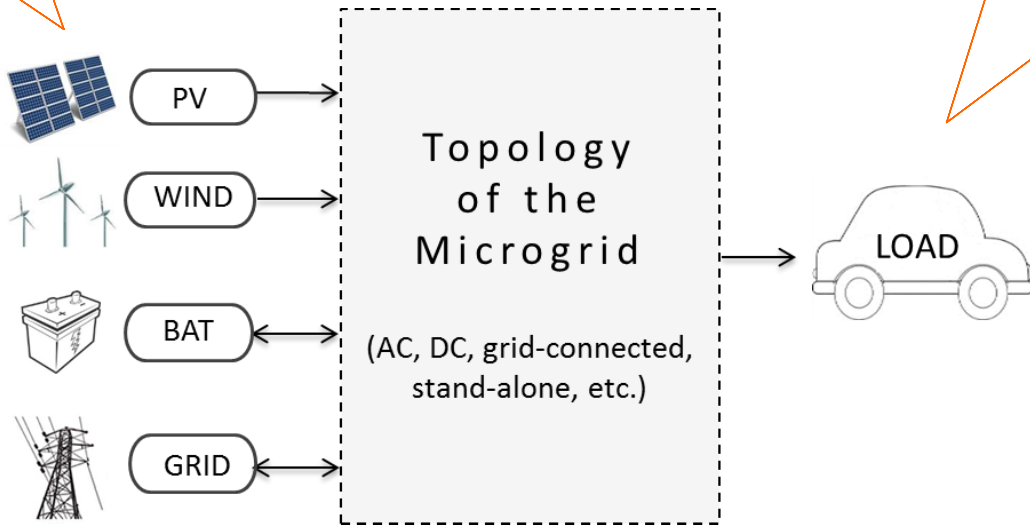


Research questions:

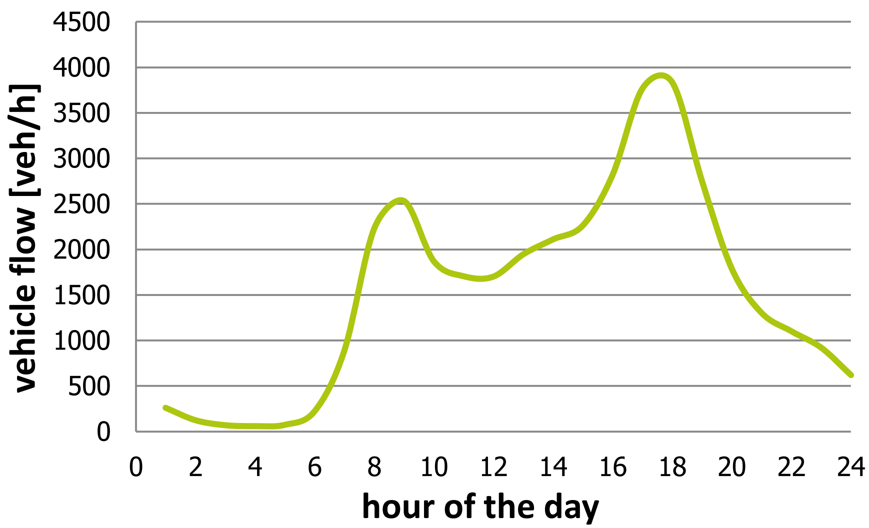
- **Data (wind speed, solar irradiance)**
- **Components specifications,**
- **Optimum Operation**

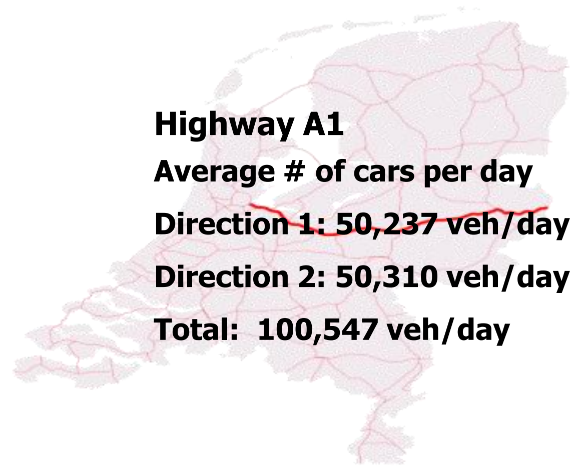
- **Optimum Topology**
- **Sizing of components**
- **Power Management**

- **Driving Pattern in the Netherlands**
- **Power consumption of Electric Vehicles**
- **Power requirements of CPT System**
- **Combine all the above**
  → **Demand curve**



Daily vehicle flow on Dutch highways





Highway A1

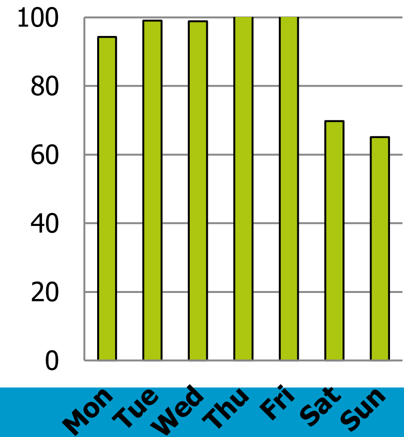
Average # of cars per day

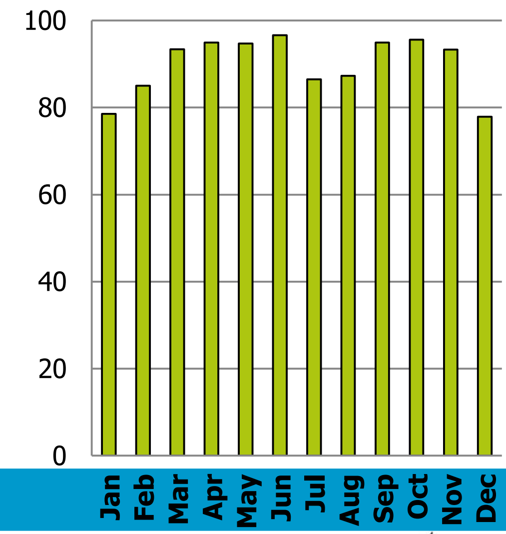
Direction 1: 50,237 veh/day

Direction 2: 50,310 veh/day

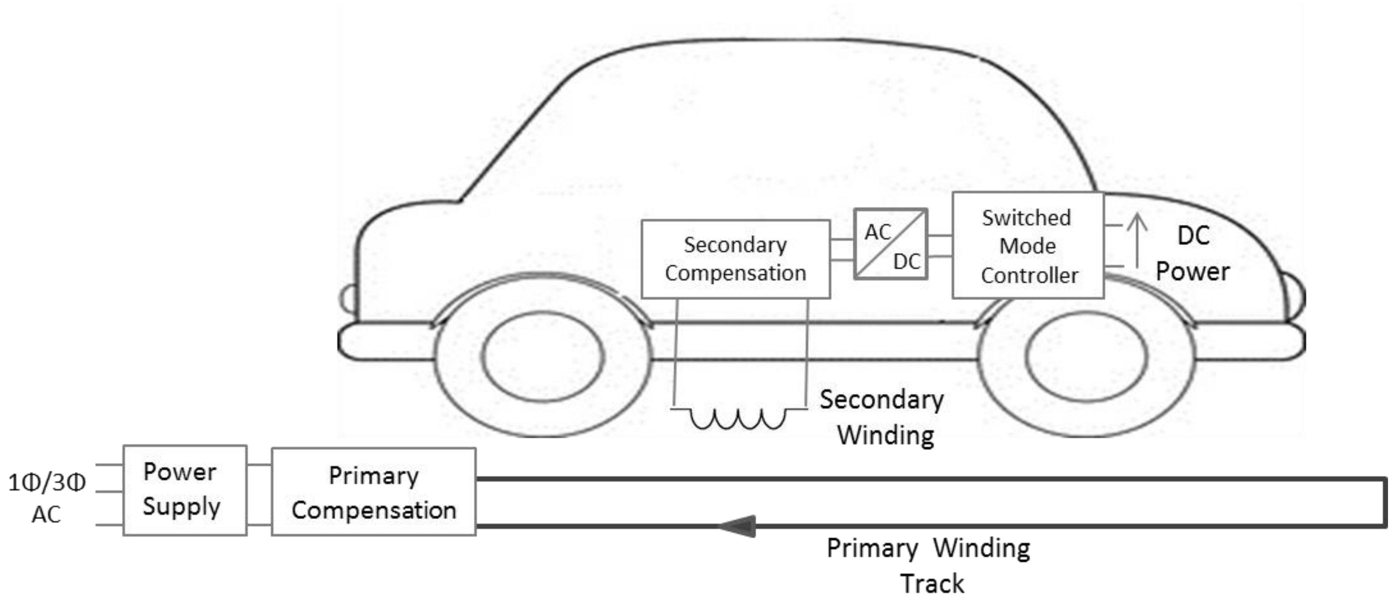
Total: 100,547 veh/day

Week & month Variations:

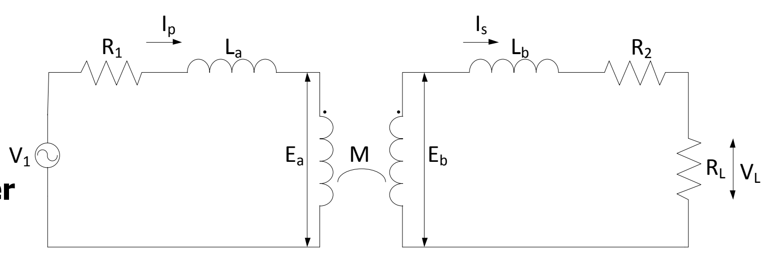




Contactless Power Transfer System for charging-while-driving

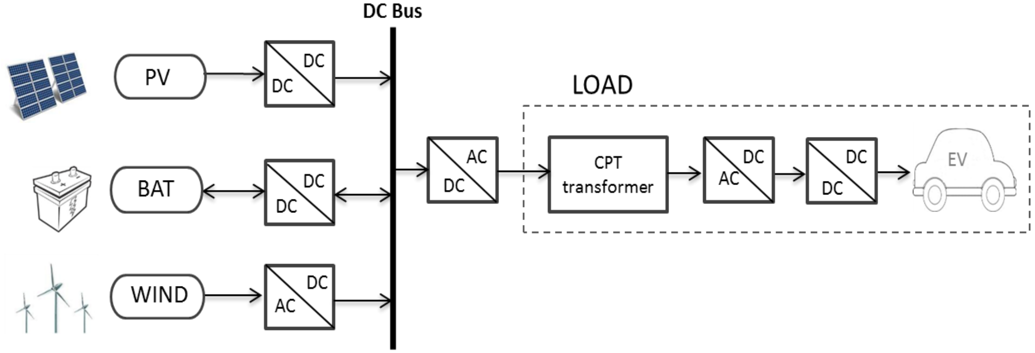


Equivalent Circuit Of CPT transformer

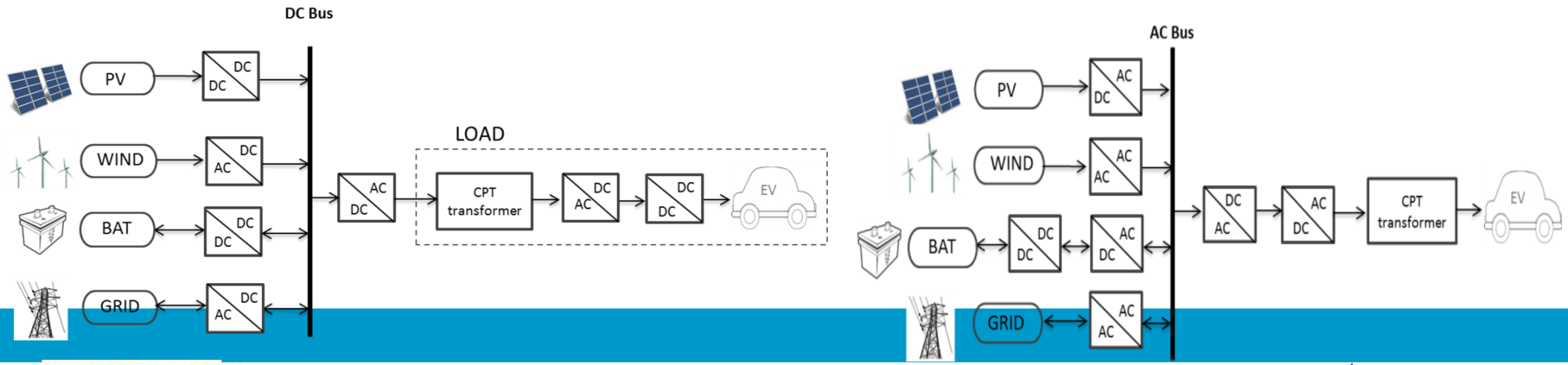


Stand Alone versus Grid Connected

- **Stand-alone operation**

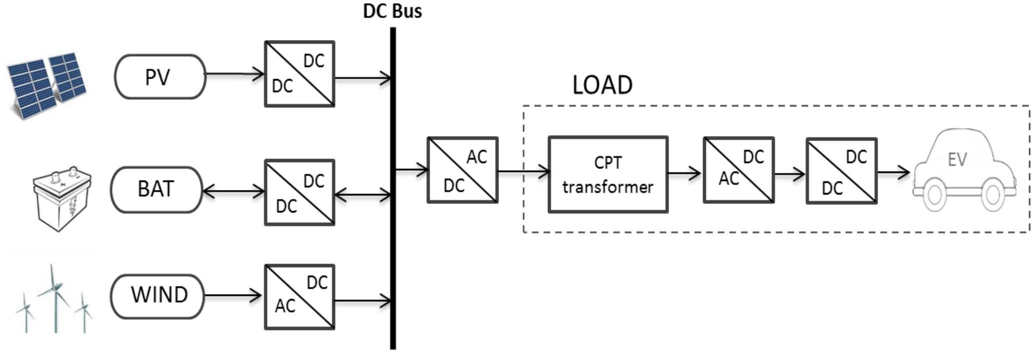


- **Grid-Connected operation**

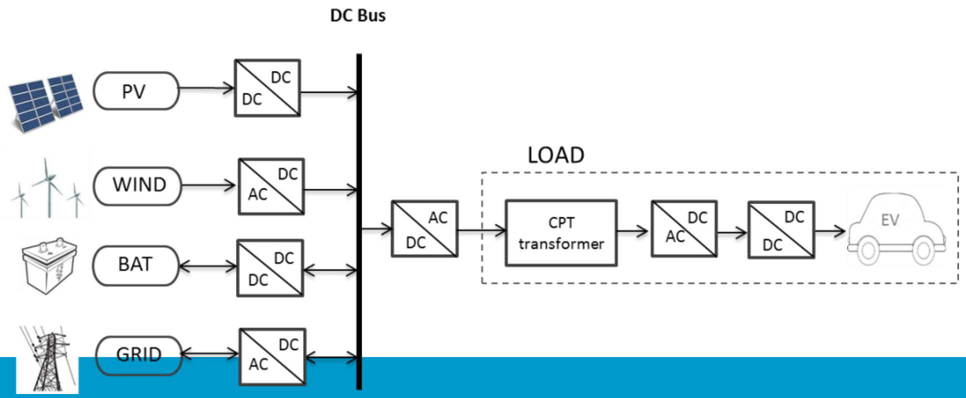


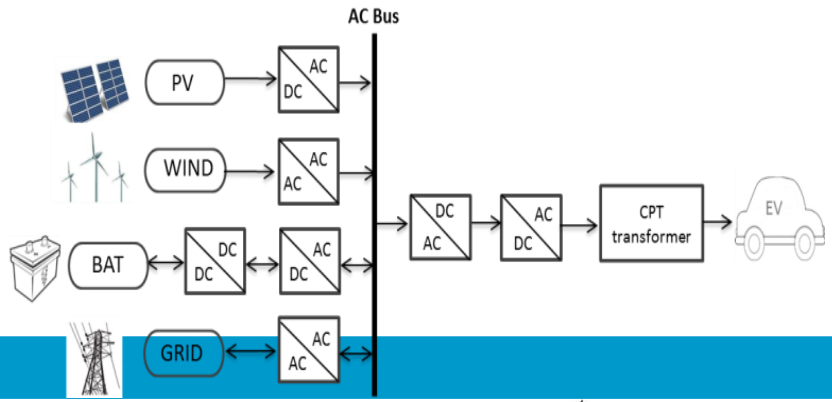
Stand Alone versus Grid Connected

- Stand-alone operation

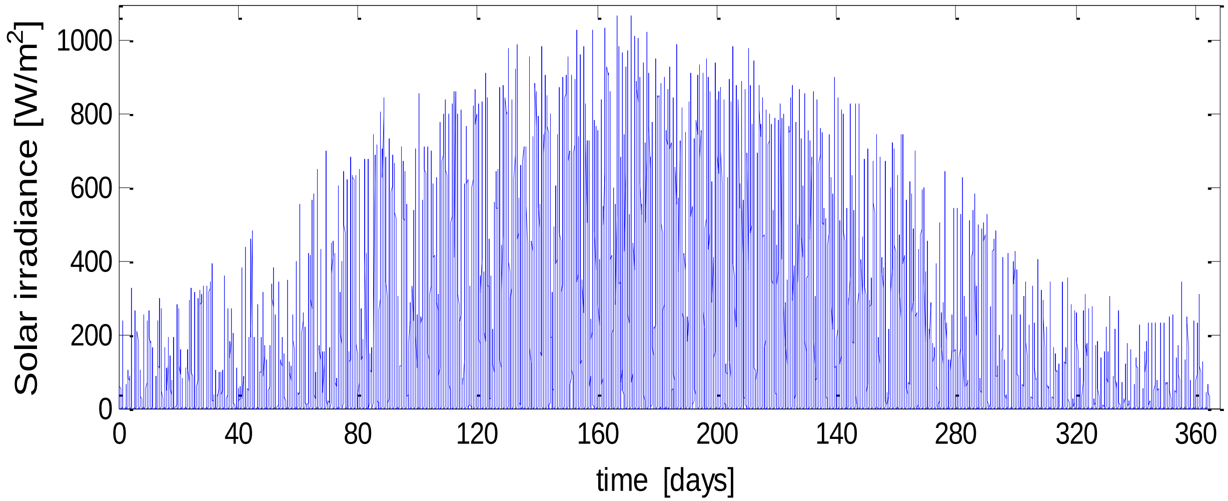


- Grid-Connected operation



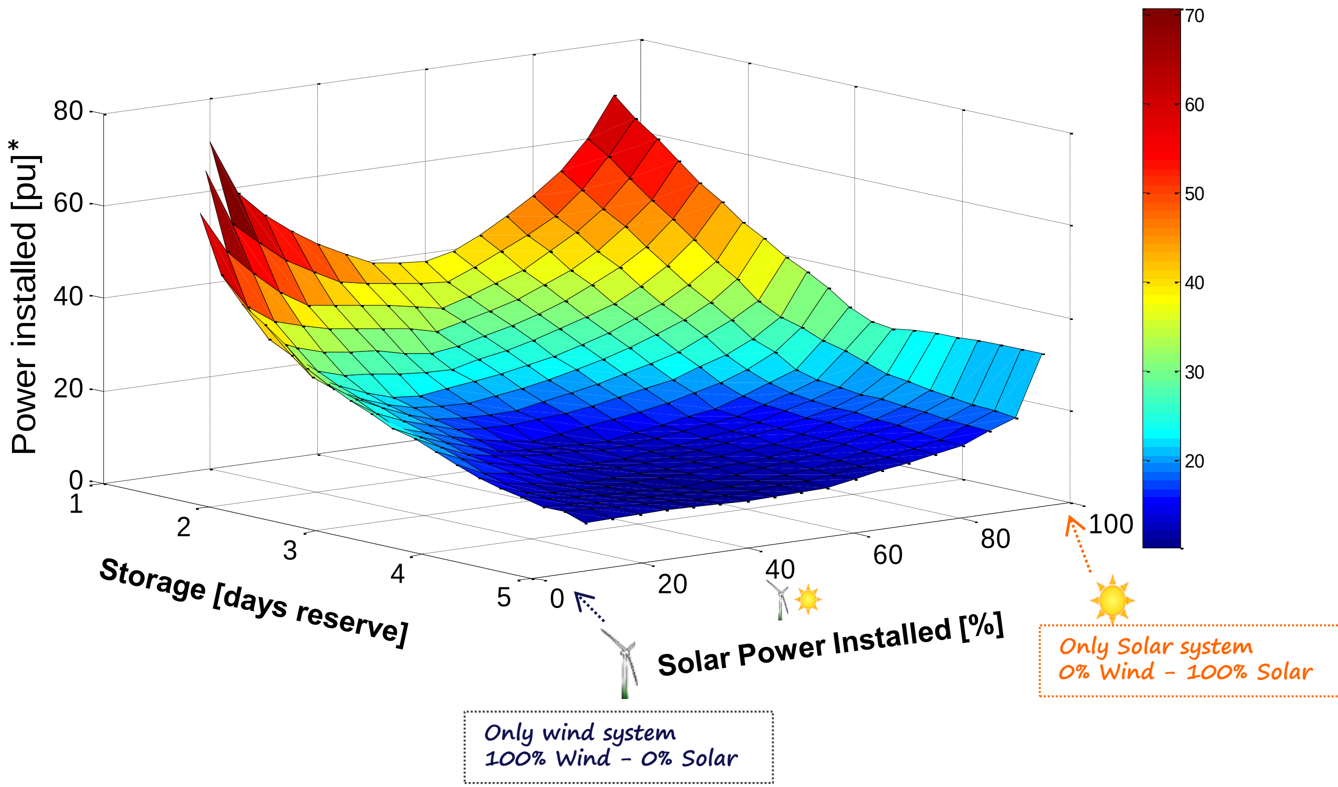


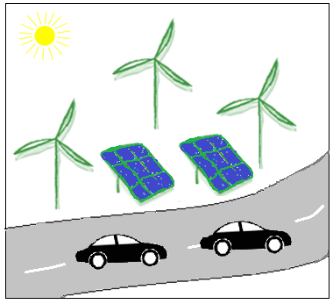
Solar and wind



The daily traffic of the road (number of cars per kilometer)
Penetration of electric vehicles (percentage to the vehicles passing)
The length of the simulated road
The specifications of the on-road CPT system

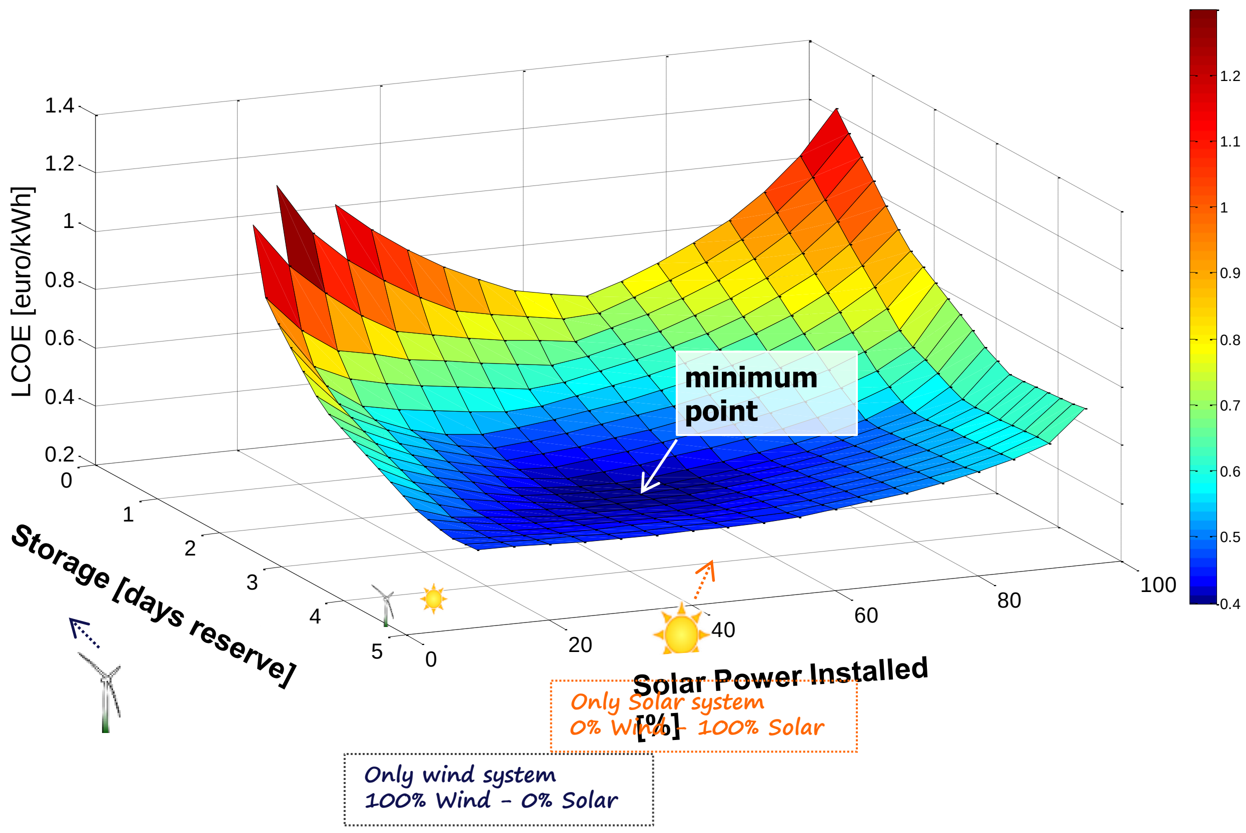
Sizing of Stand-Alone microgrid

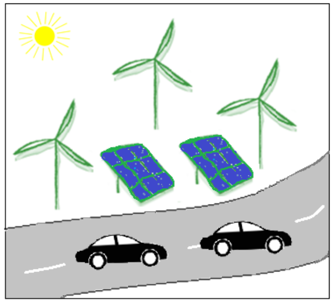




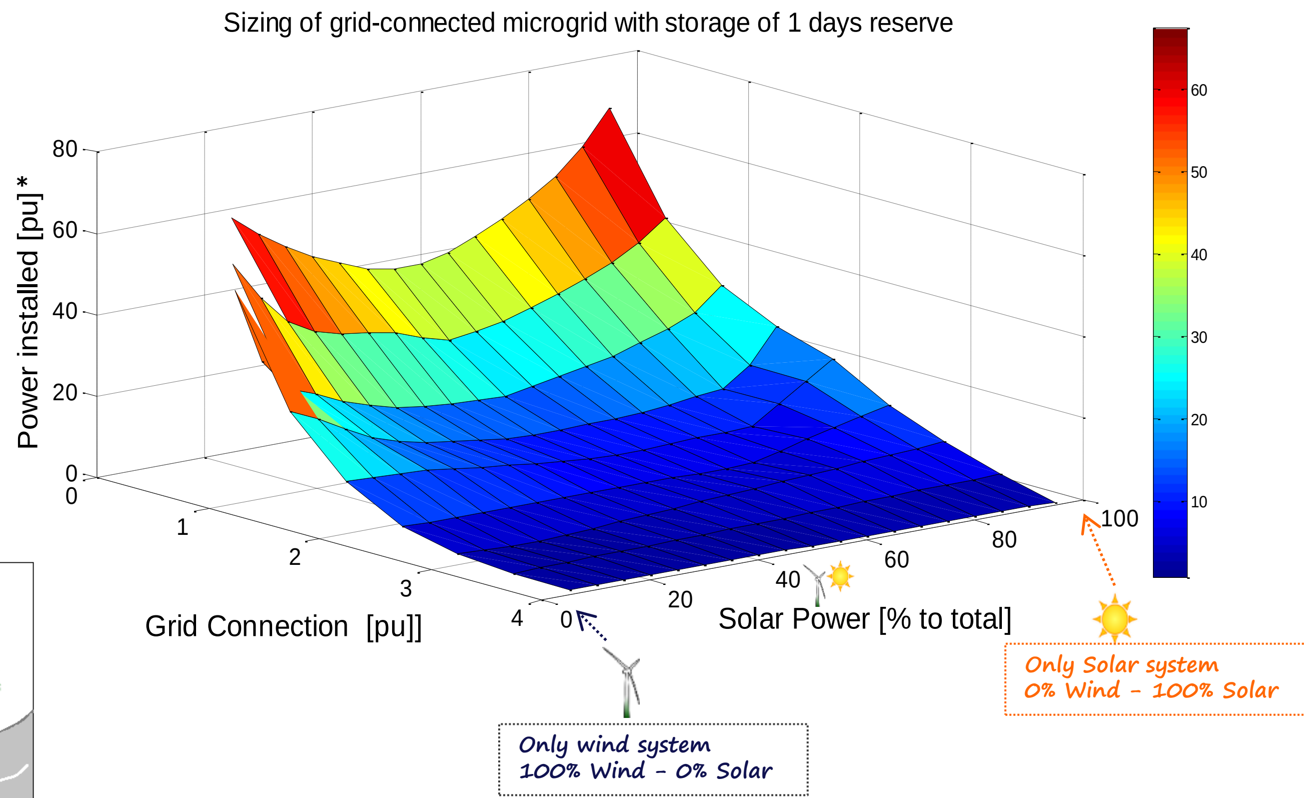
* 1 pu = average yearly demand

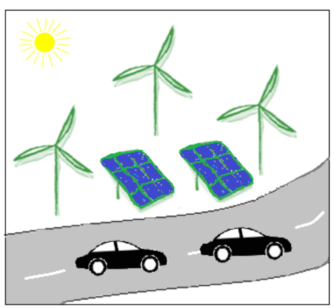
Cost Analysis of Stand-Alone microgrid





Sizing of grid-connected microgrid





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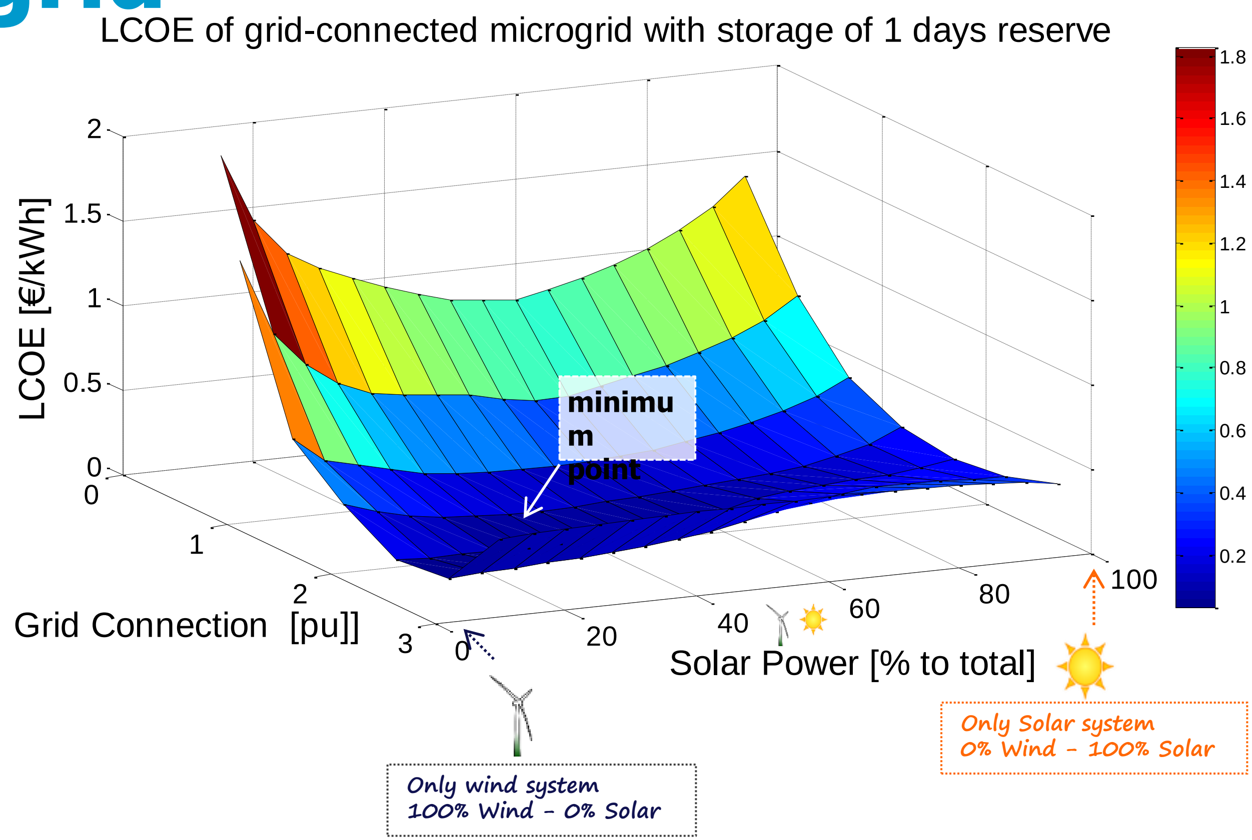
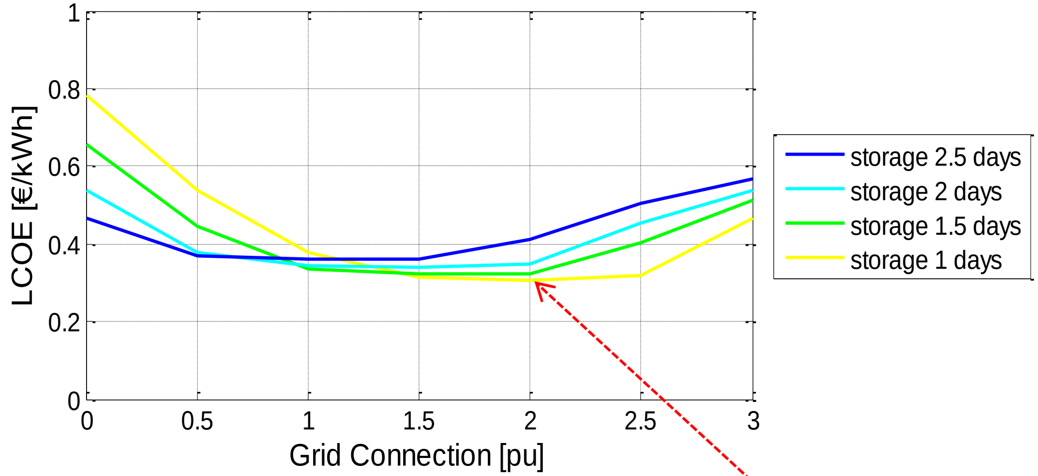
Cost Analysis of grid-connected microgrid



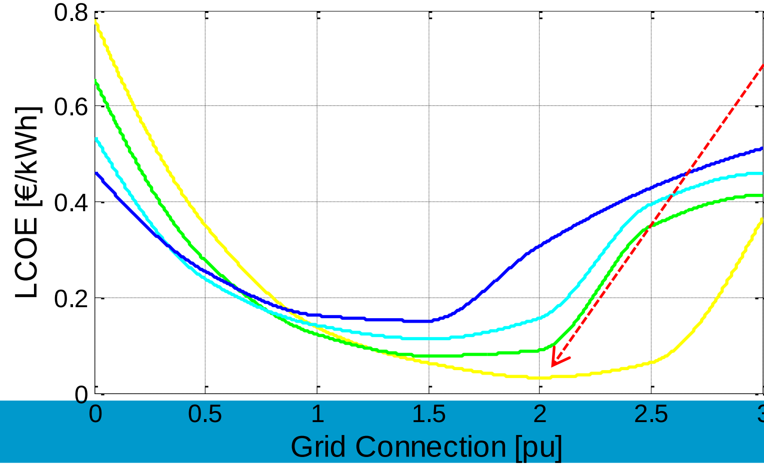
Minimum Cost Points

- **considering only investment cost:**



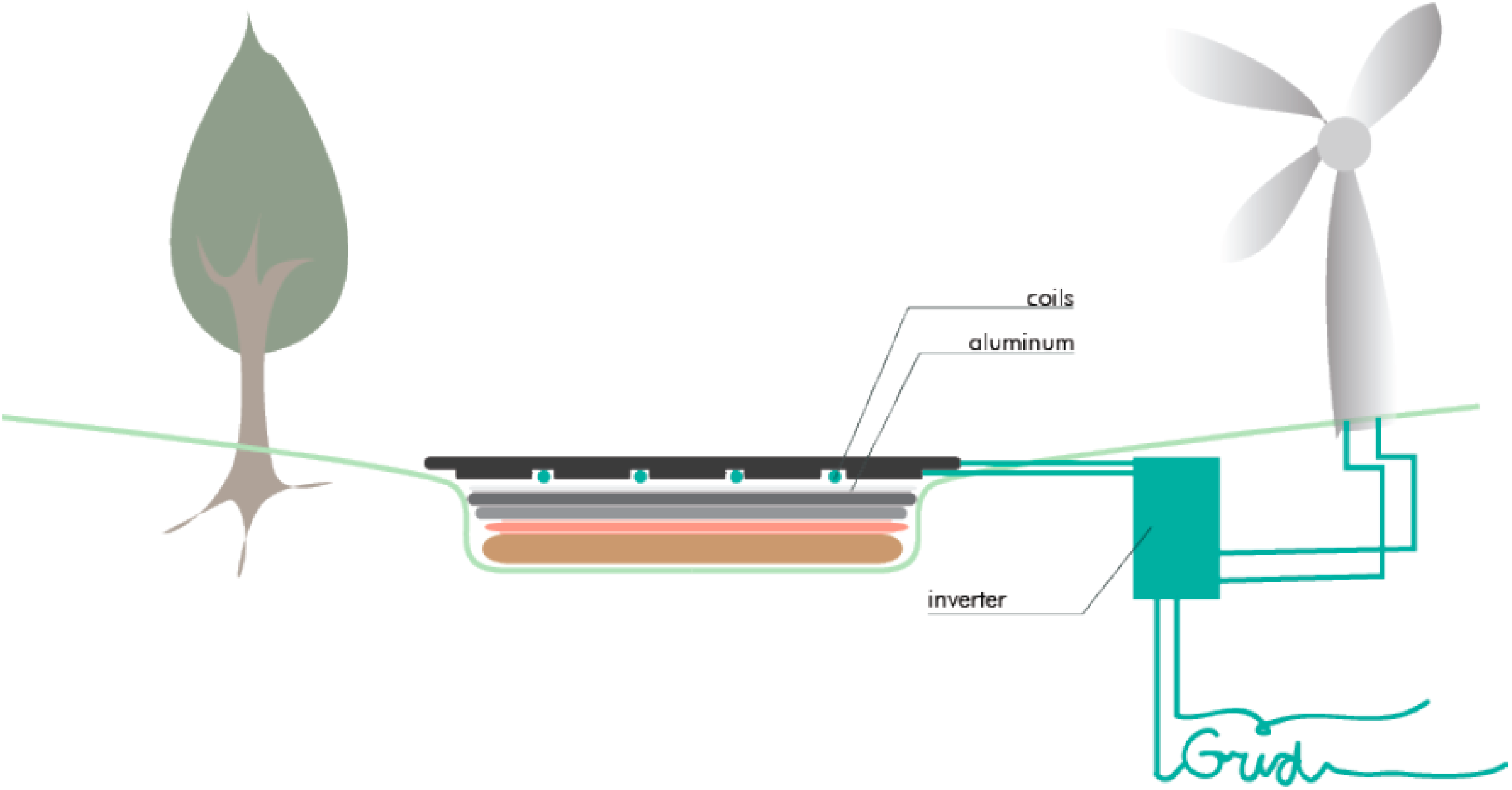
Minimum cost

- **considering the revenues from selling power:**



Minimum Cost Point	
Storage	1 day
Grid connection	2 p.u.
Total power installed	8 p.u.

Future roads

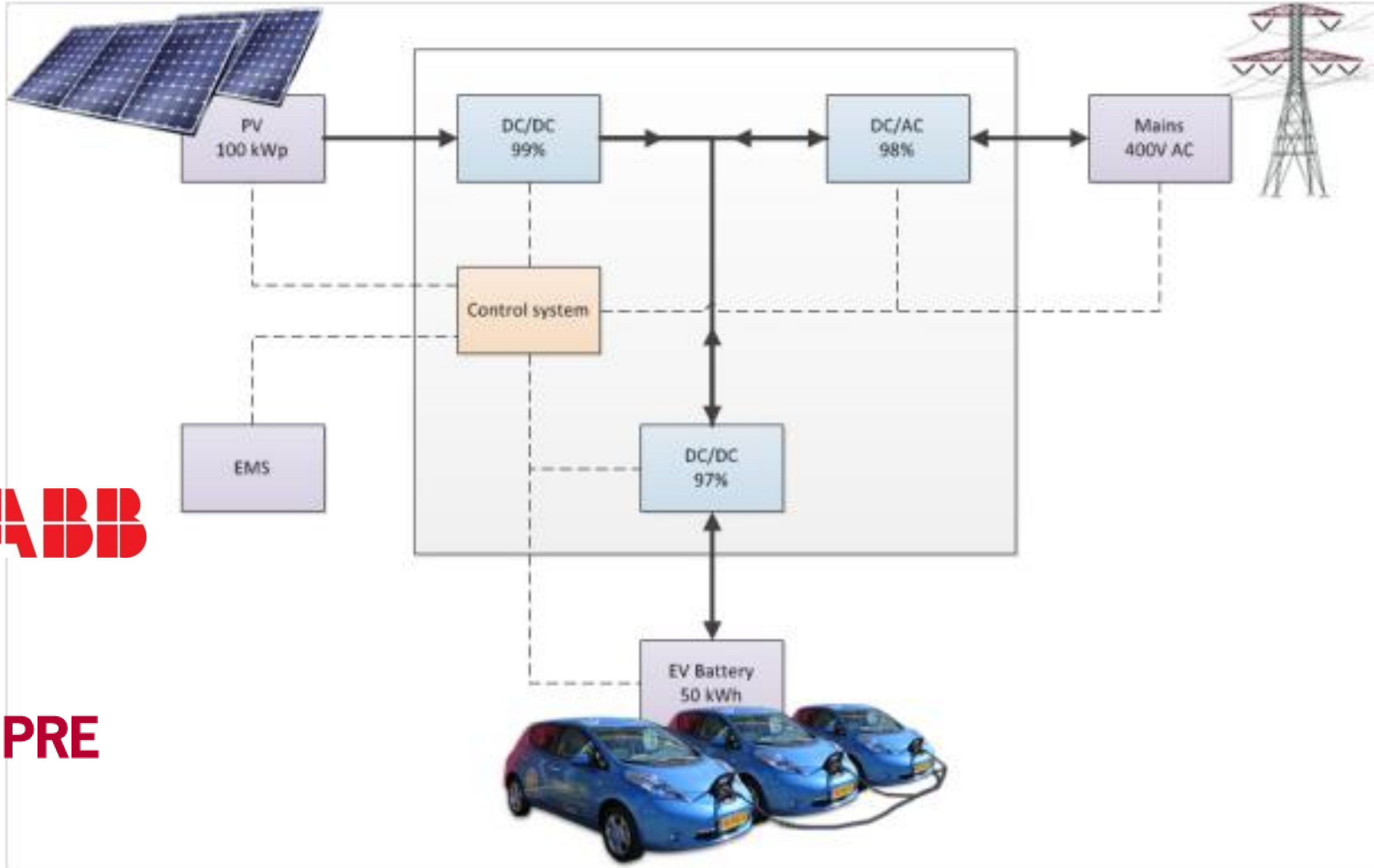


Let us invent the future

- Roads powering electrical vehicles
- Self healing roads
- Roads generating sustainable energy
- Roads allowing automated driving

PV Cha

PV Charging of EVs

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