# Hybrid Drive Systems for Vehicles

L9 - Charging



# Static Charging

# On board / Off board = AC / DC



Off board ⟵ ⟶ On board

- **”AC Charging”**
- **Automation missing**
- **High power plug missing?**
- 10...100 MW/m$^2$

- **”Wireless Charging”**
- 10...100 kW/m$^2$

- **” DC Charging”**
- **Automation missing**
- 10...100 MW/m$^2$

# Who needs an Automatic Charging Connection … ?

- **Commercial Vehicles**
  - *May be Opportunity Charged up to 10 … 20 times a day*
  - *The power level is high!*
  - *Automatic connection **absolutely necessary !!!***

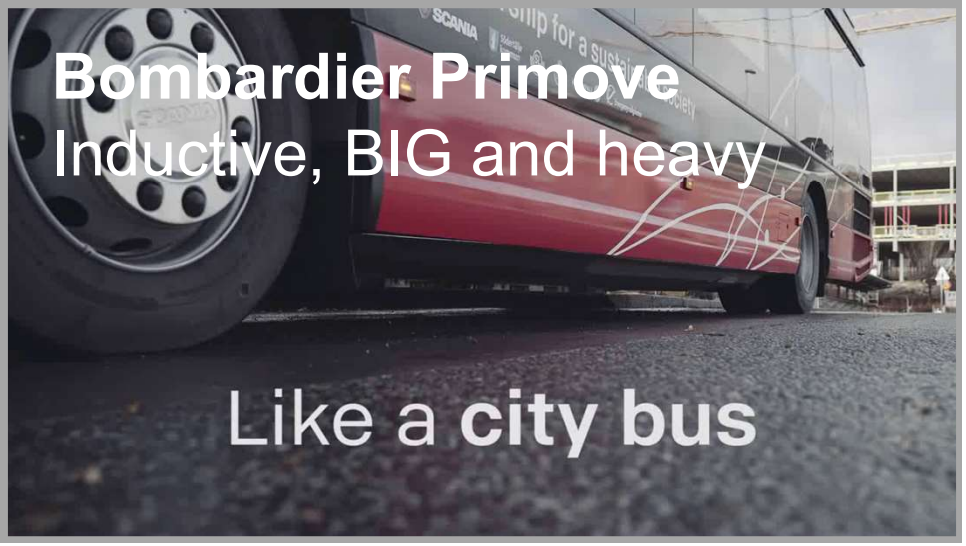

- **Autonomous private (?) vehicles**
  - *Maybe a Spotify/Netflix/Uber kind of vehicle*
  - *Must be able to autonomously arrange washing, charging, workshop visit, …*
  - Usually connected 1…3 times per day
  - *Automatic connection **absolutely necessary !!!***

**OPPcharge**
Panto on infra = Low Bus cost

OPPcharge
a common interface for opportunity charging

**ABB TOSA**
Panto on BUS, Drives bus cost

**BYD**
Manual, Low Cost Infra

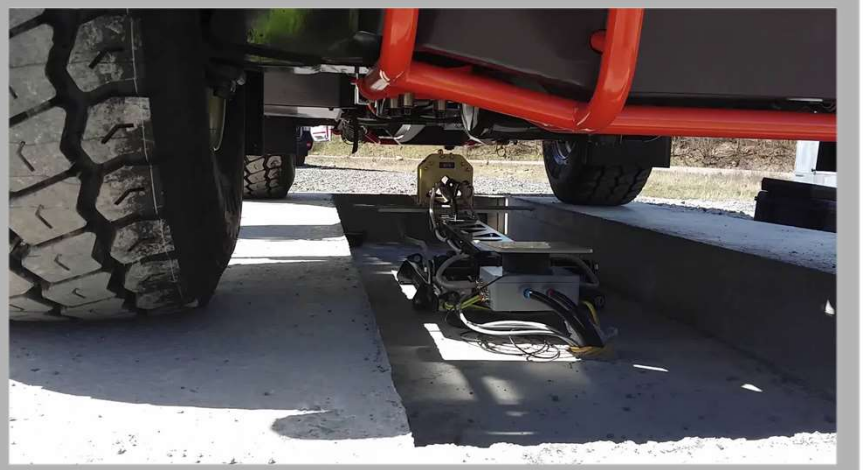


**Bombardier Primove**
Inductive, BIG and heavy

Like a **city bus**

# Even the Car industry is trying ...

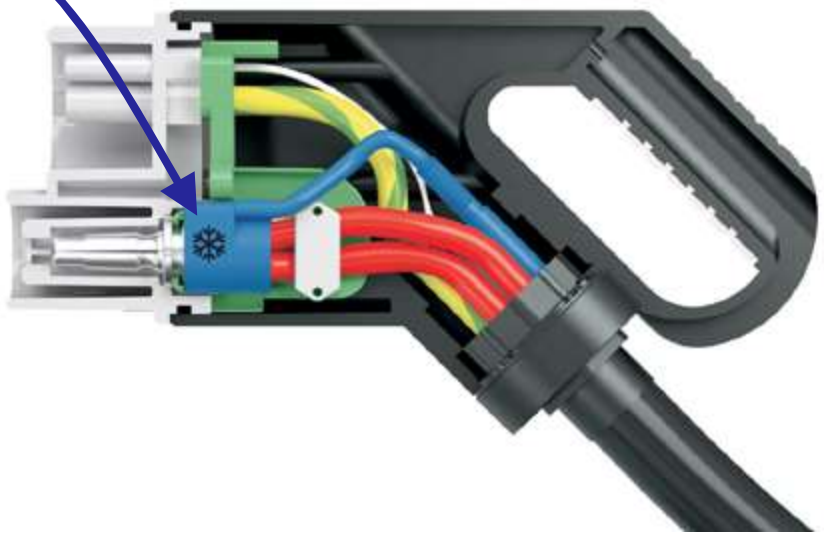
# And also Off Road ....



# The gardening industry is leading ...

# But we are still pushing the limits …

- Same CCS-plug, now called ”CCSplus”, boosted with water cooling.
- Current limits pushed towards 350 Ampére and beyond.
  = 260 ... 500 kW, depending
- Still no automation!



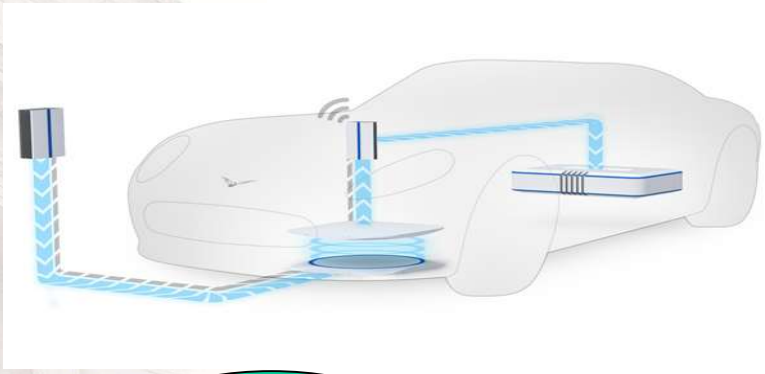
# Normal fuse levels

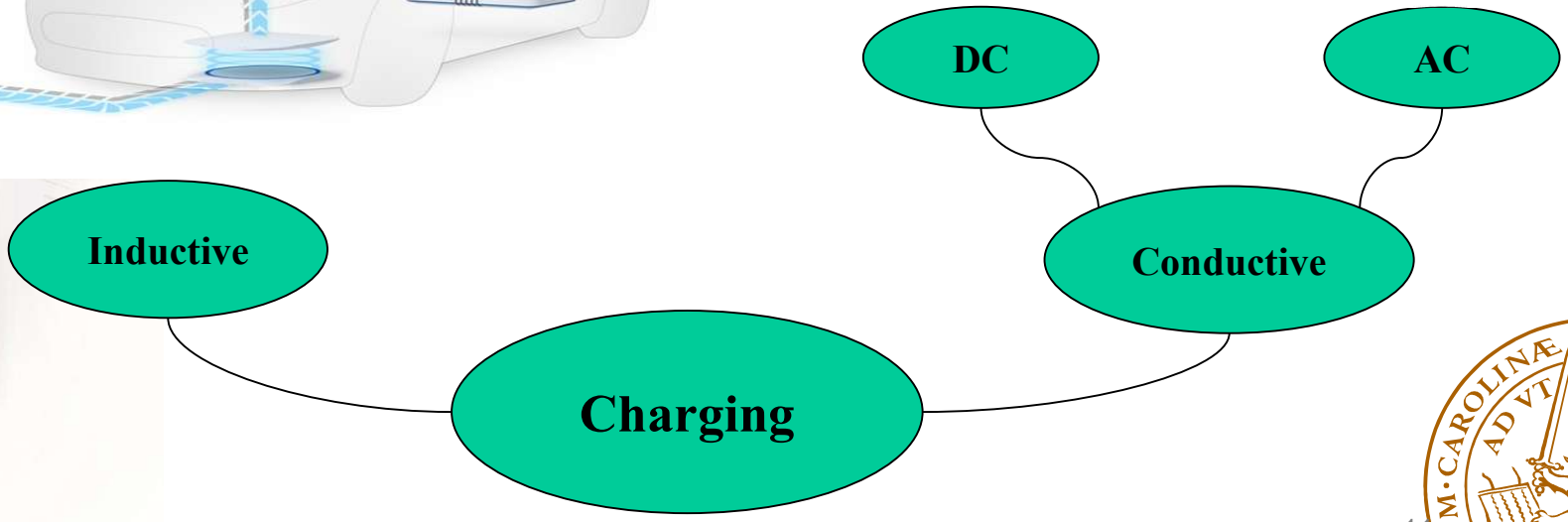
- **Home**
  - 1 phase
    - 10 Ampére -> 2,3 kW
    - 16 Ampére -> 3,7 kW

- **Other places**
  - 3 phase
    - 16 Ampére -> 11 kW
    - 32 Ampére -> 22 kW
    - 63 Ampére -> 44 kW
    - 125 Ampére -> 87 kW

| Voltage range | Frequency range | Colour code |
|---|---|---|
| 20– 25 V | 50/60 Hz | Purple |
| 40– 50 V | 50/60 Hz | White |
| 100–130 V | 50/60 Hz | Yellow |
| 200–250 V | 50/60 Hz | Blue |
| 380–480 V | 50/60 Hz | Red |
| 500–690 V | 50/60 Hz | Black |
| - | >60–500 Hz | Green |
| None of the above | | Grey |

# Charging Mind Map





# Dedicated Charging Stations





# Historical Perspective on EV Charging Equipment 1900 to Today ….and Tomorrow

## 1913- 150A/48vdc coupler (30,000 EVs in 1913)

*The electric vehicle - raising the standards*

*Figure 3.25: 150 A charging plug with handle*[108]

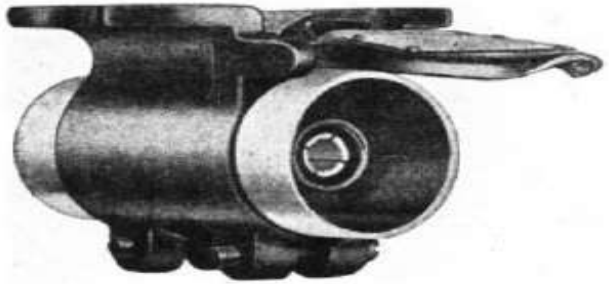
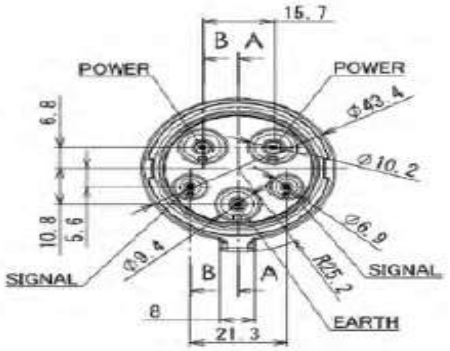


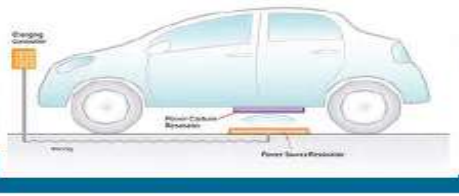
*Figure 3.26: 150 ampere-hour (sic) charging receptacle*[109]

## 1990's J1772 Conductive SAE J1773 Inductive

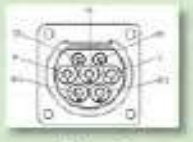
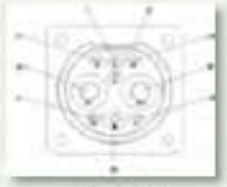
## 2010 SAE J1772 Level 2 240vac/<80A (32A typ.)




## 2011 SAE J2954 Wireless Charging

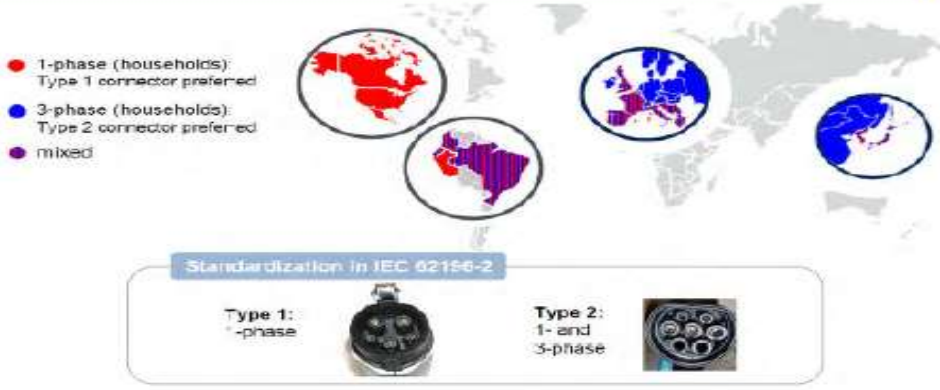


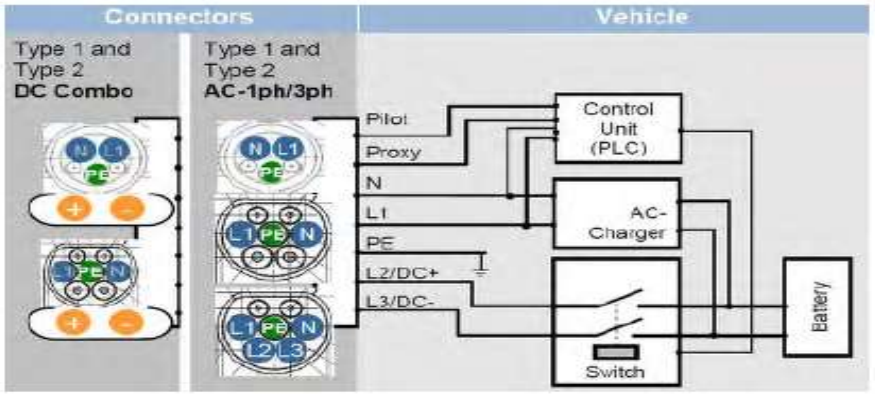
# Global Differences in Connectivity

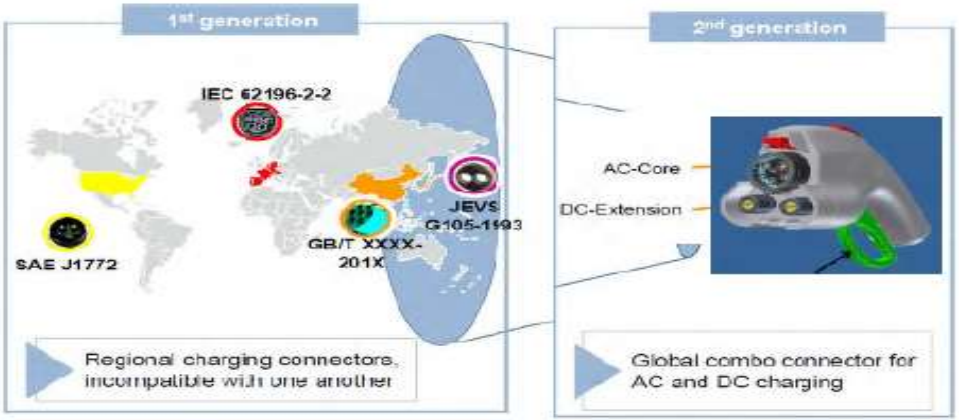
| | | US | EU | | CHINA | JAPAN |
|---|---|---|---|---|---|---|
| AC Charging | Single-Phase (1Ø) |  SAE J1772™ |  IEC 62196-2 Type 1 | *SAE and IEC AC standards have common control signals* |  Type 2 |  SAE J1772™ * |
| | Single- or Three-Phase (1Ø or 3Ø) | |  IEC 62196-2 Type 2<br>  IEC 62196-2 Type 3 | | *China charge couplers (not standard yet) have unique control signals and overall physical shape* | *Japan CHADEMO standard has unique control signals and overall physical shape* |
| DC Charging | |  SAE J1772™ 'Hybrid' |  IEC 62196-2 Type 2 'Hybrid' | *SAE and IEC working toward harmonization of DC 'Hybrid' charge couplers* |  Mode 3 |  JEVS G105-1993 (CHADEMO) |

*SAE J1772™ AC connector has also been adopted by Korea and Australia

# AC/DC Connector Standards Around the World

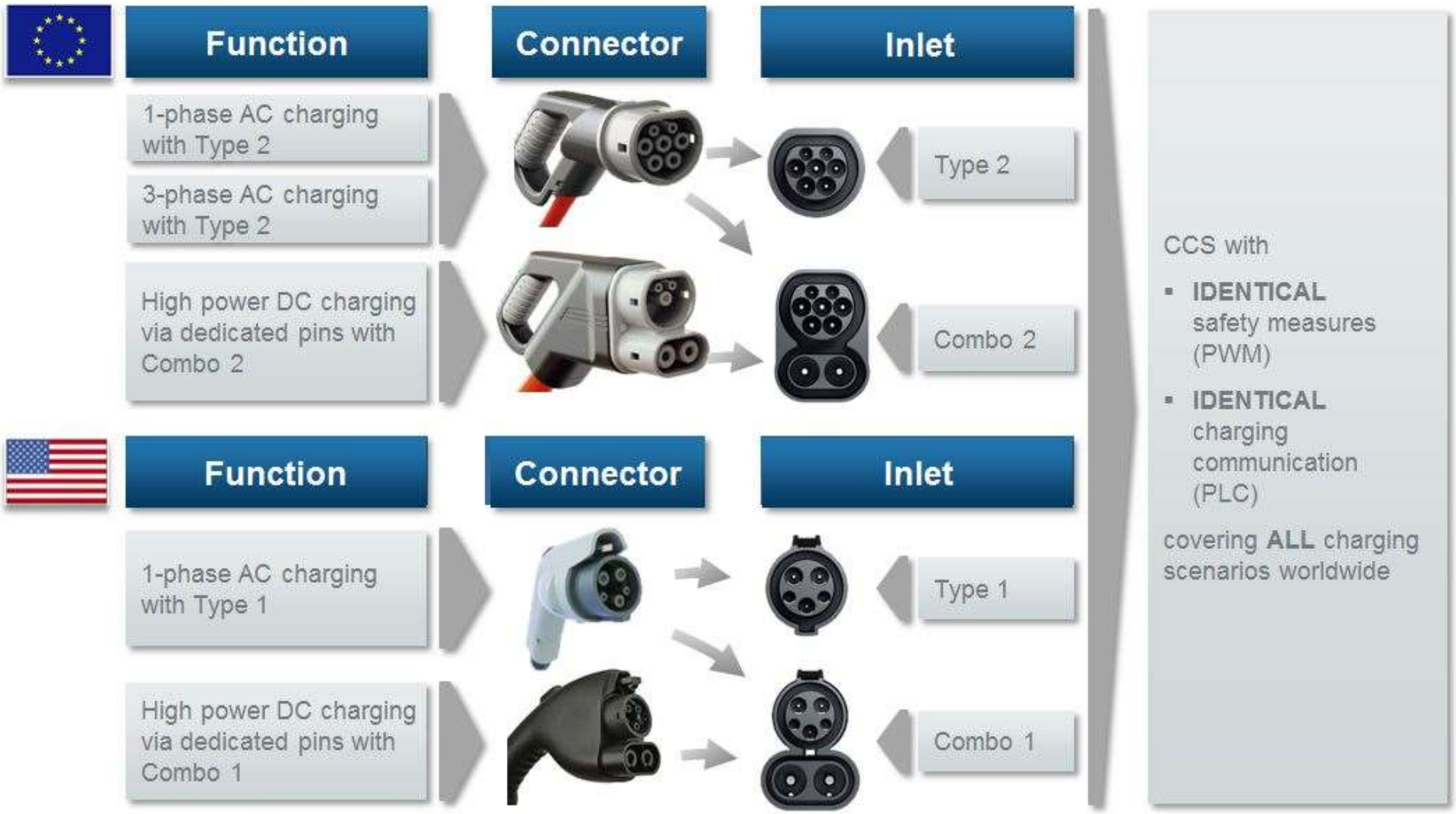


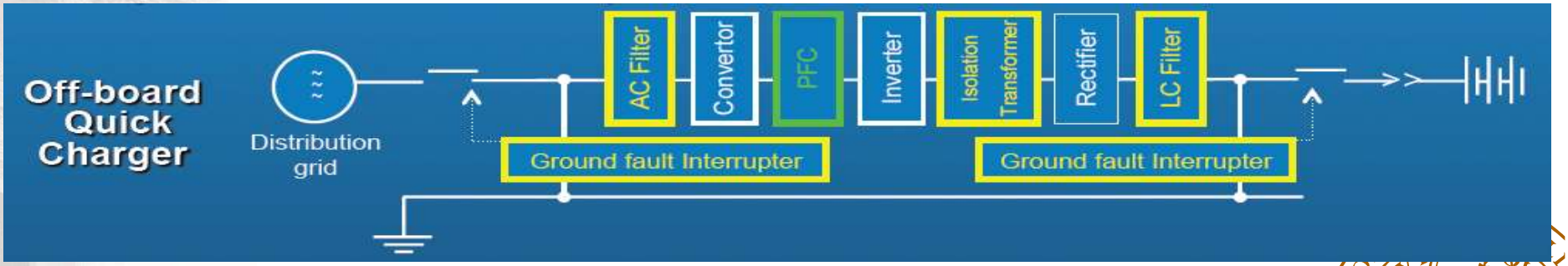

A detailed analysis of design options confirmed the feasibility of lean design.

| | Option 1 Reuse of AC PINs Typ 1 | Option 1 Reuse of AC PINs Typ 2 | Option 2 Selfcontained DC Typ 1 | Option 2 Selfcontained DC Typ 2 |
|---|---|---|---|---|
| Var.A PLC only | 85 x 90 (mm) | 75 x 100 | 85 x 110 | |
| Var.B CAN additional | 85 x 95 | 80 x 100 | 85 x 110 | |
| Var.C Interlock and CAN | 95 x 105 | 85 x 105 | 85 x 120 | |


Function
Connector
Inlet
1-phase AC charging with Type 2
3-phase AC charging with Type 2
Type 2
High power DC charging via dedicated pins with Combo 2
Combo 2
Function
Connector
Inlet
1-phase AC charging with Type 1
Type 1
High power DC charging via dedicated pins with Combo 1
Combo 1
CCS with
IDENTICAL safety measures (PWM)
IDENTICAL charging communication (PLC)
covering ALL charging scenarios worldwide

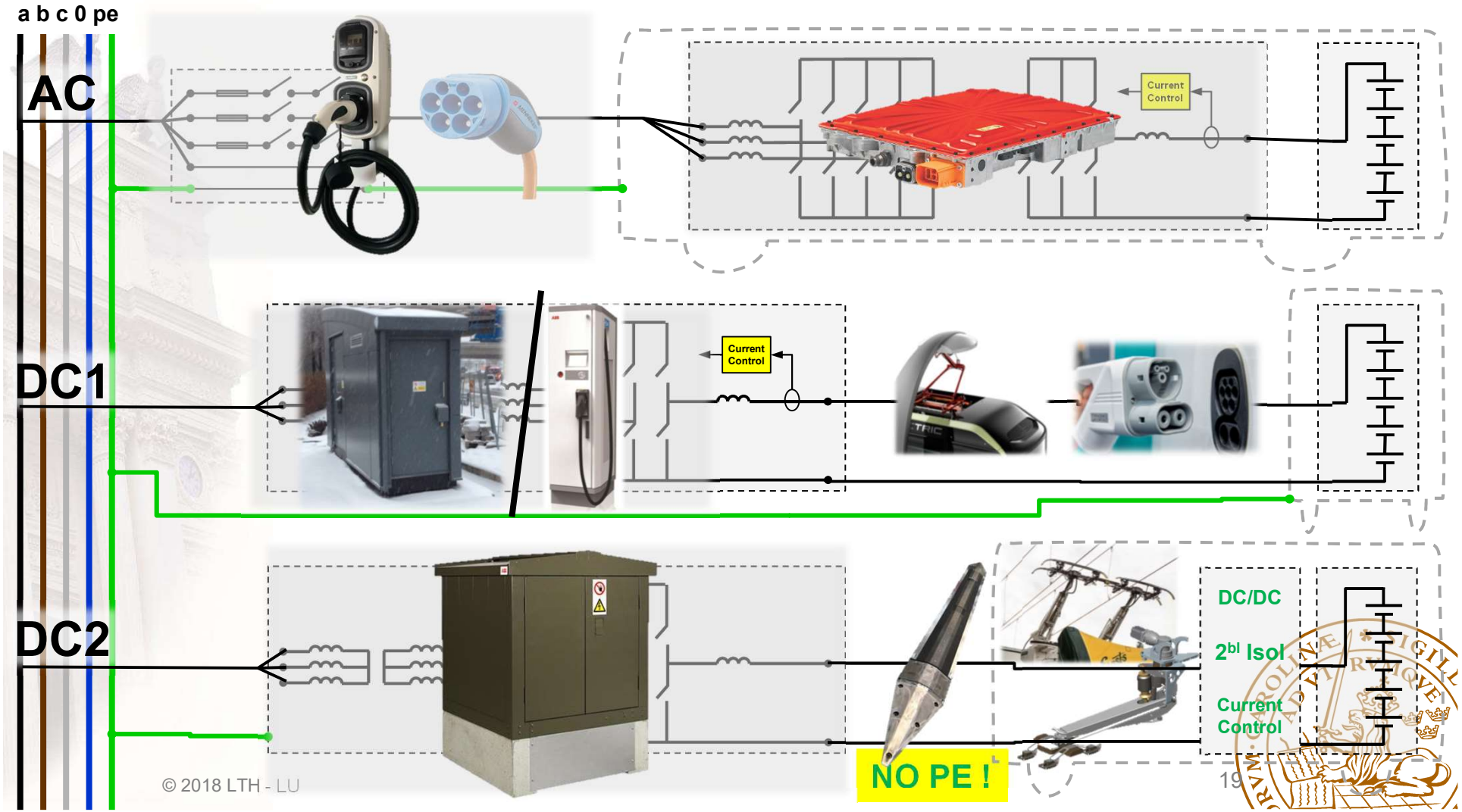
# The Chademo Charging Sta

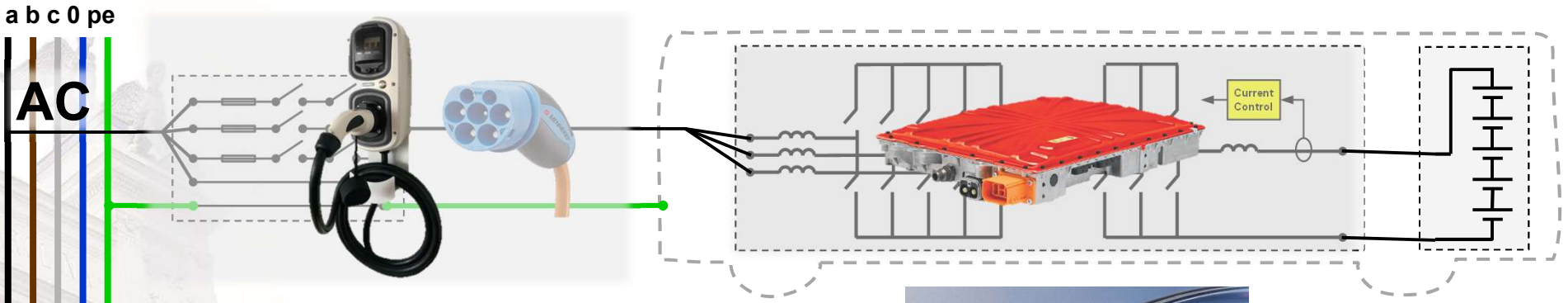
CHAdeMO



# Chademo suppliers

| | | | | | | | |
|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  |
| SGTE (France) | ABB (Switzerland) | EVTRONIC (France) | Efacec (Portugal) | Aerovironment (America) | Aker Wade (America) | Delta Electronics (Taiwan) | Petrotec (Portugal) |
|  |  |  |  |  |  |  |  |
| MAGNUM CAP (Portugal) | GH Electrotermia (Spain) | Schneider (France) | SIGNET Systems (Korea) | DBT (France) | ECOtality NA (America) | Circontrol (Spain) | EVTEC (Switzerland) |
|  |  |  |  |  |  |  |  |
| Hasetec | Takaoka | Takasago | NS-ELEX | Kyuden Technosystems | ULVAC | Fuji Electric | NEC |
|  |  |  |  |  |  |  |  |
| SINFONIA TECHNOLOGY | Nichicon | Nissan | GS Yuasa | JFE Engineering | Kikusui | NTT Facilities | HITACHI |


a b c 0 pe
AC
Current Control
DC1
Current Control
DC2
DC/DC
2bl Isol
Current Control
NO PE !




- 3 phase plug limited to 63 A
- Max charging power 44 kW
- Available from all OEMs for night time charging

- E.g. 200 kWh in 5 hours night time.

- NOT Enough for Opportunity Charging at +100 kW? There is a possibility!

- New Plug Needed for higher power levels!

DC&AC
63 -> 150 A/pin
= 104 kW AC

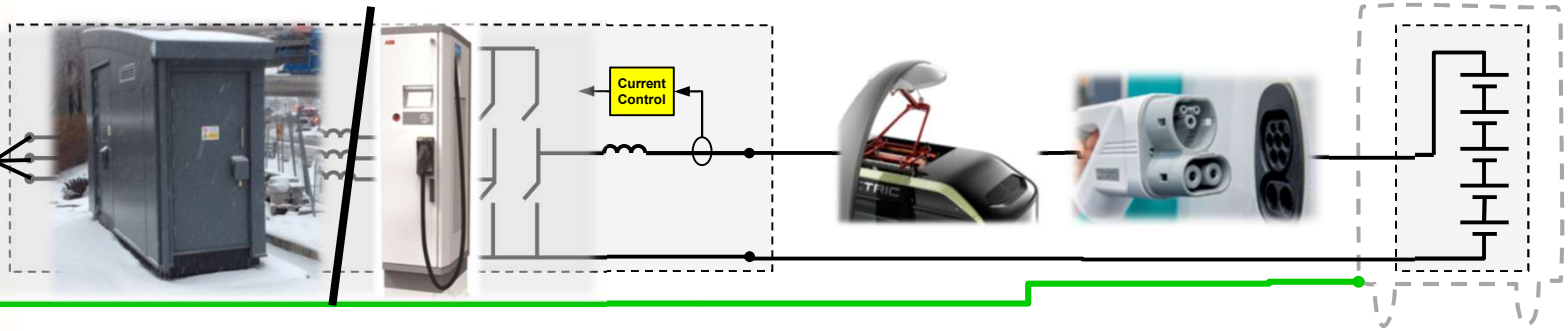
a b c 0 pe

AC

DC1

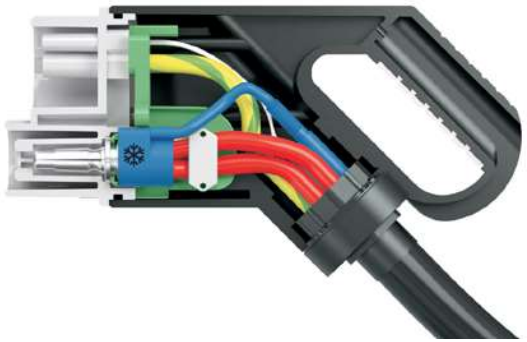
DC2

- OppCharge an open ”standard”, capable of up to 600 kW
- Expensive stations, not compatible with most truck applications




- CCS/DC normally limited to 200 A.
- @ 750 V this gives 150 kW, e.g 4x0.25h = 150 kWh
- NOT automatic

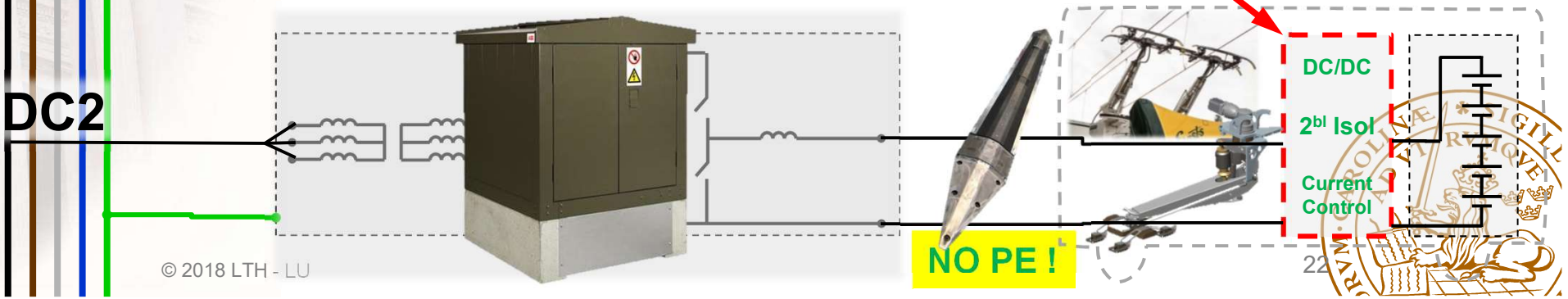
- Pushed towards 500 A with water cooling = 375 kW @ 750 V



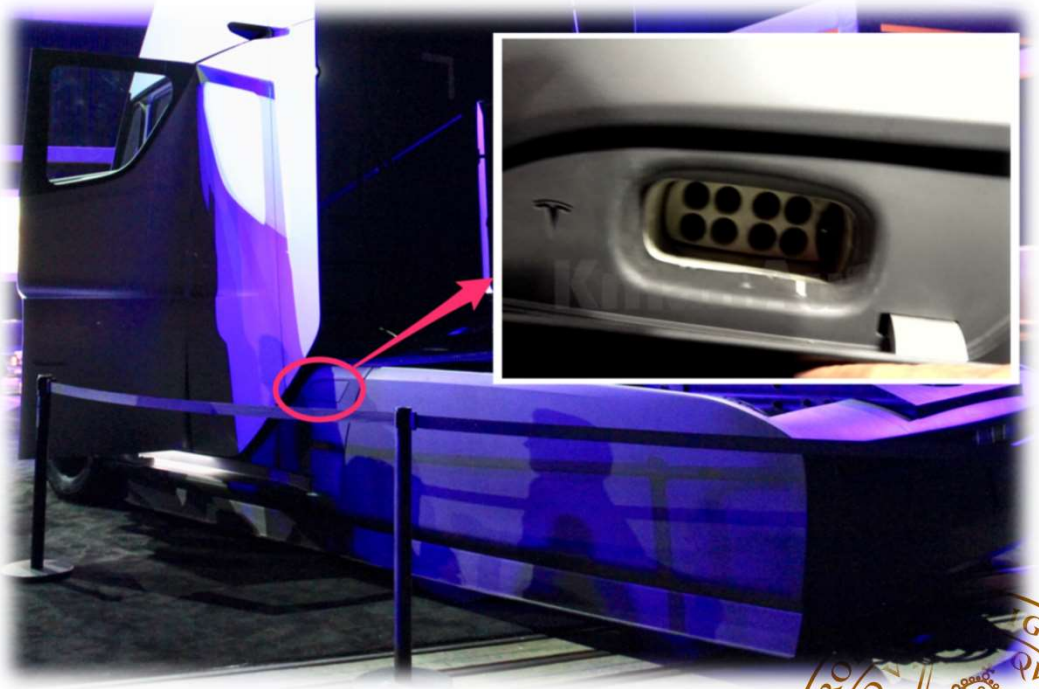
a b c 0 pe

- Siemens eHighway is currently leading
- Others follow very soon
- Significant battery size reduction (-60%...-80%)
- 150 kWh instead of 600 kWh

- No protective earth – requires special safety solutions

# Tesla Semi Analysis ...



# Technical facts

## Given Facts

- GVW = 80000 lbs = 36 287 kg
- Drag Coefficient = Cd = 0.36
- Drivetrain: 4 PM motors from Model 3
- Acceleration 0-60 mph = 0-97 km/h
  - Tractor only: 5 seconds
  - Full load (80000 lbs): 20 seconds
- Hill climbing: 5 % slope @ 65 mph = 105 km/h
- Range: 300/500 miles = 483/805 km
- Charging time: 400 miles = 644 km in 30 minutes

## Calculated Facts

- Energy consumption = about 1 kWh/km
- Tractor weight = 9 tons
- Traction motors = 4 x 137/192 kW (cont/peak)
- Battery Energy = 850 – 950 kWh (depends on DoD)
- Battery Weight = 4.2 – 4.7 tons (@ 0.2 kWh/kg)
- Charging power

  = almost 1.3 Megawatt for Fast Charging

  = 100 kW for Night Time Charging
- MEGA Charging Connector: Seems to be 4xSUPER Charging Connector

X 4 =

# The Perfect Charging Connection …

Is **automatic**

Works with both
**small** and **BIG** vehicles

Can be used both when
**standing still and when moving**

Can be used both
**in the city and on the highway**

# Dynamic Charging

# What is Dynamic Charging ?

- Charging while the vehicle is moving
  - *Even at highway speed!*
- Inductive or Conductive
- Traditional solutions with Trams, Trolley Buses and Trains
- New Solutions emerging fast

Bombardier PRIMOVE

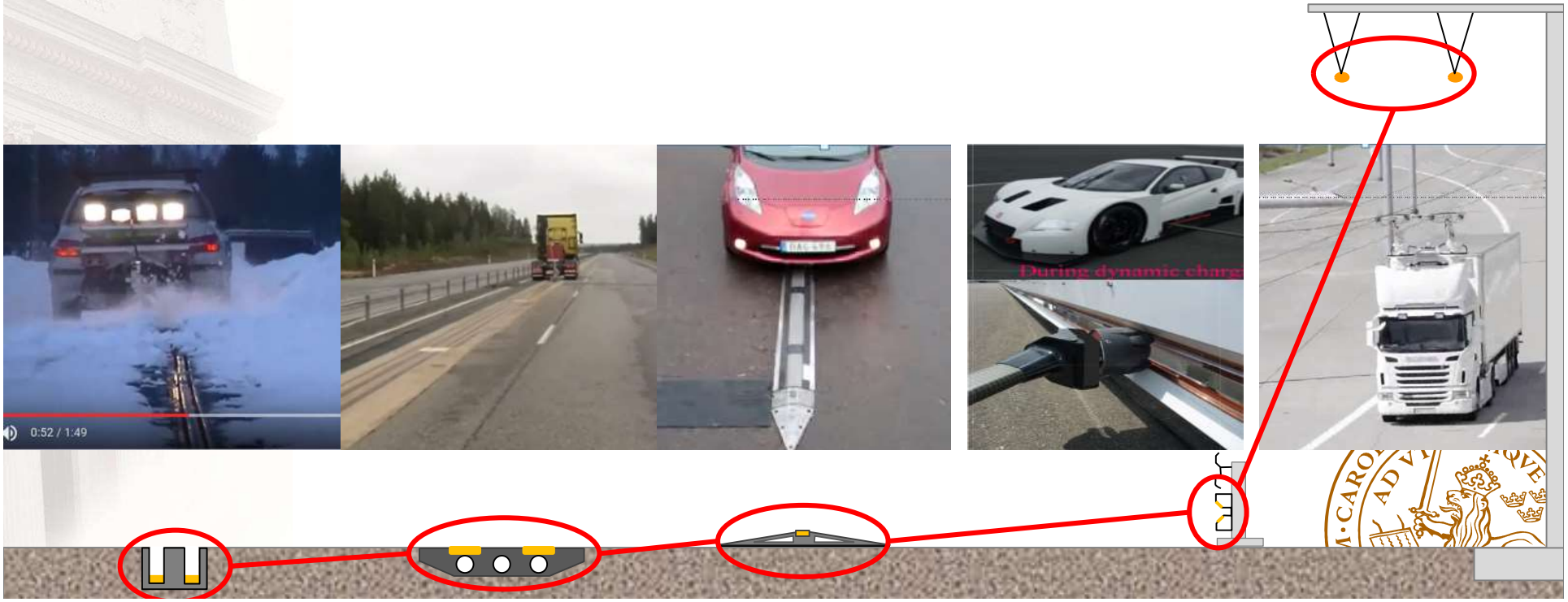
ALSTOM APS

OLEV

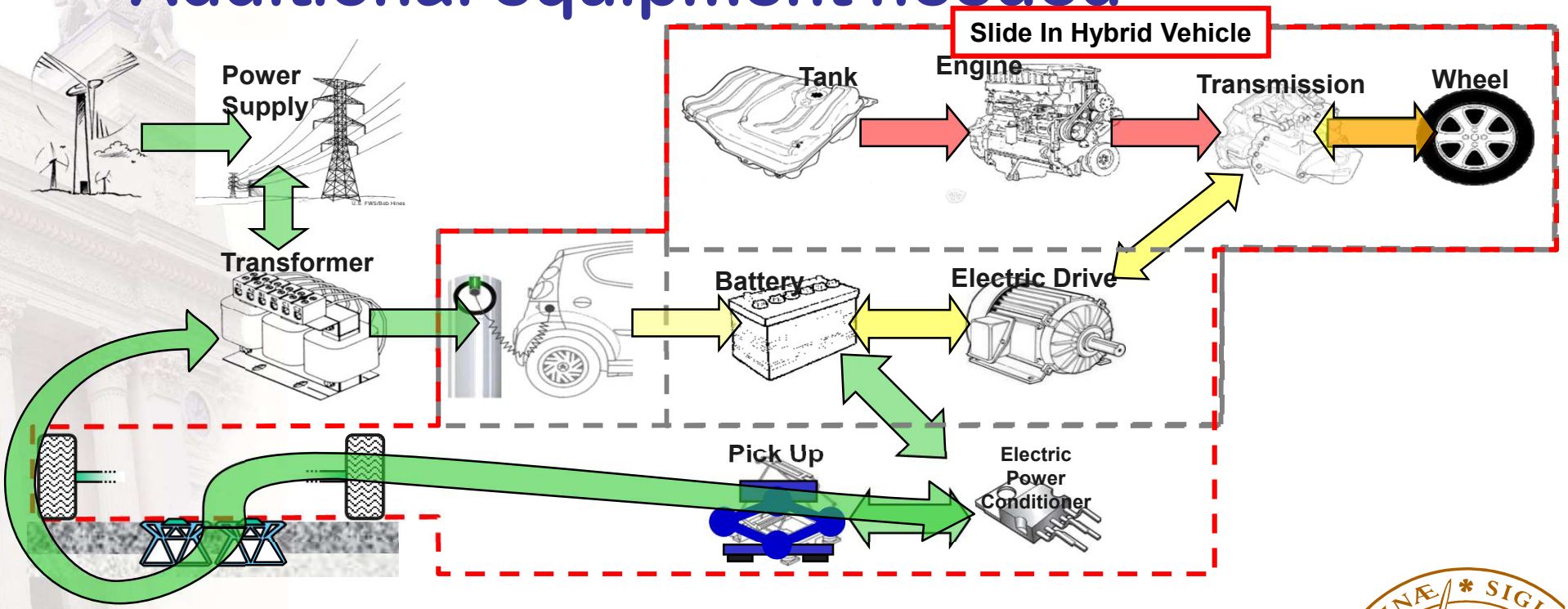
Siemens *e*Highway

# Conductive ERS concepts

Elways | Alstom | Elonroad | Honda | Siemens

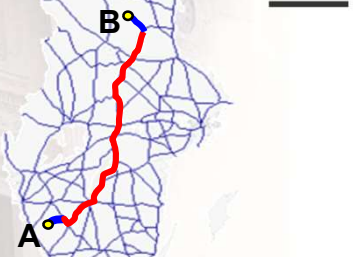


# Additional equipment needed



# Activated in sections ...

- Activated ”step by step”
- Needs little precision
- Overtaking on battery
- Reduced battery range

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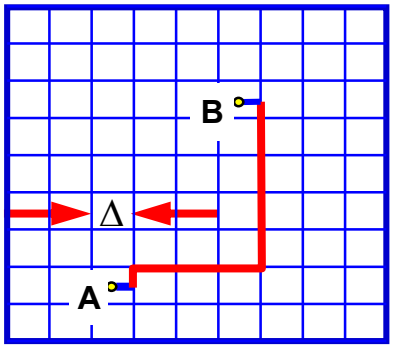
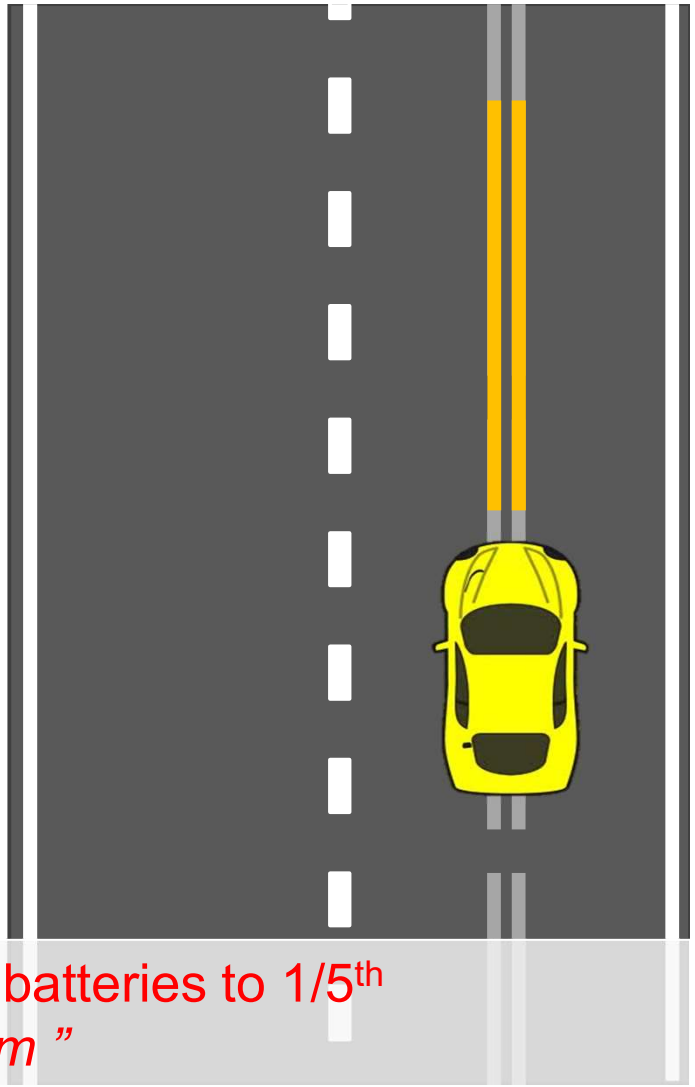
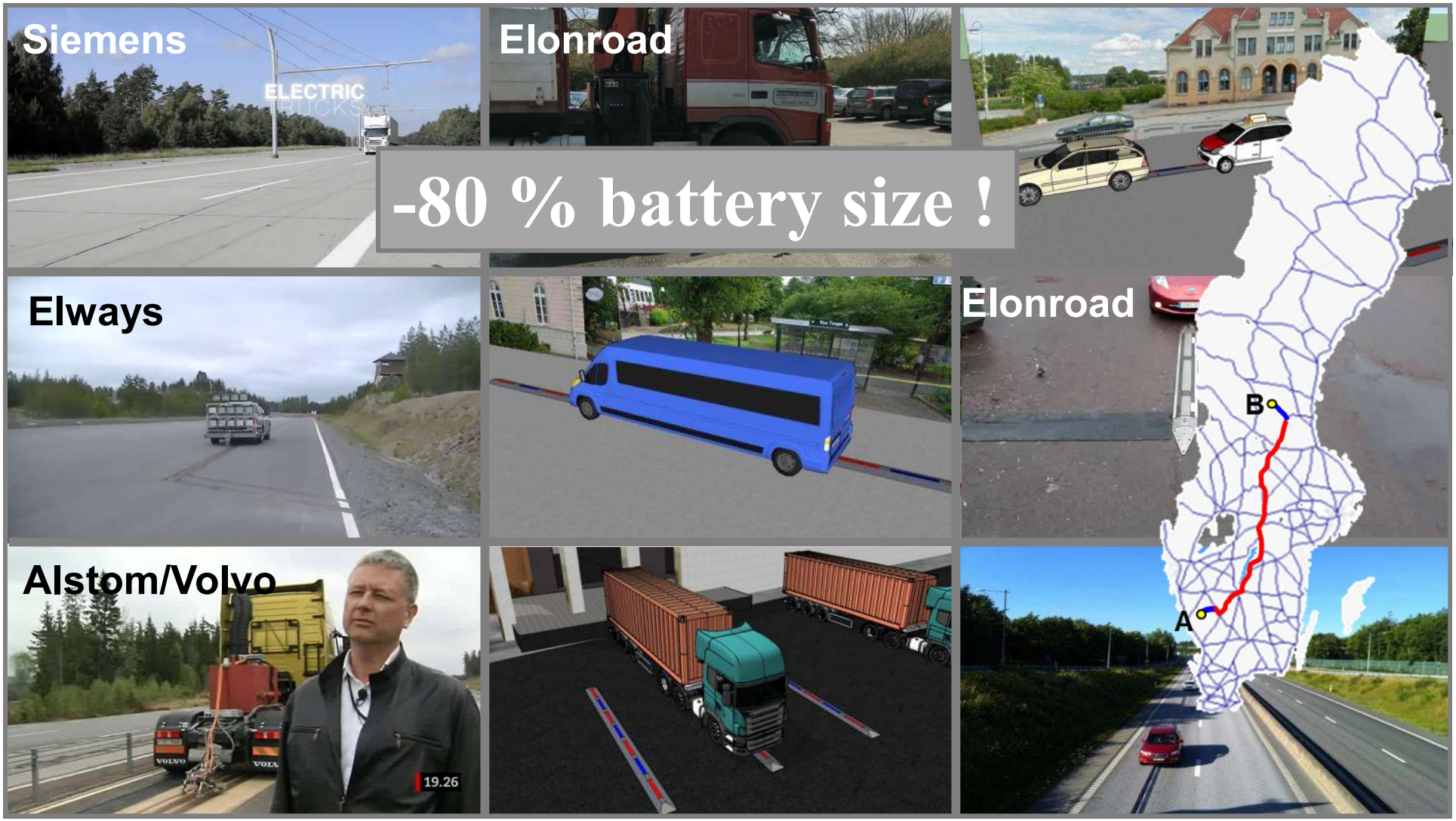



- Sweden: $\Delta = 50$ km

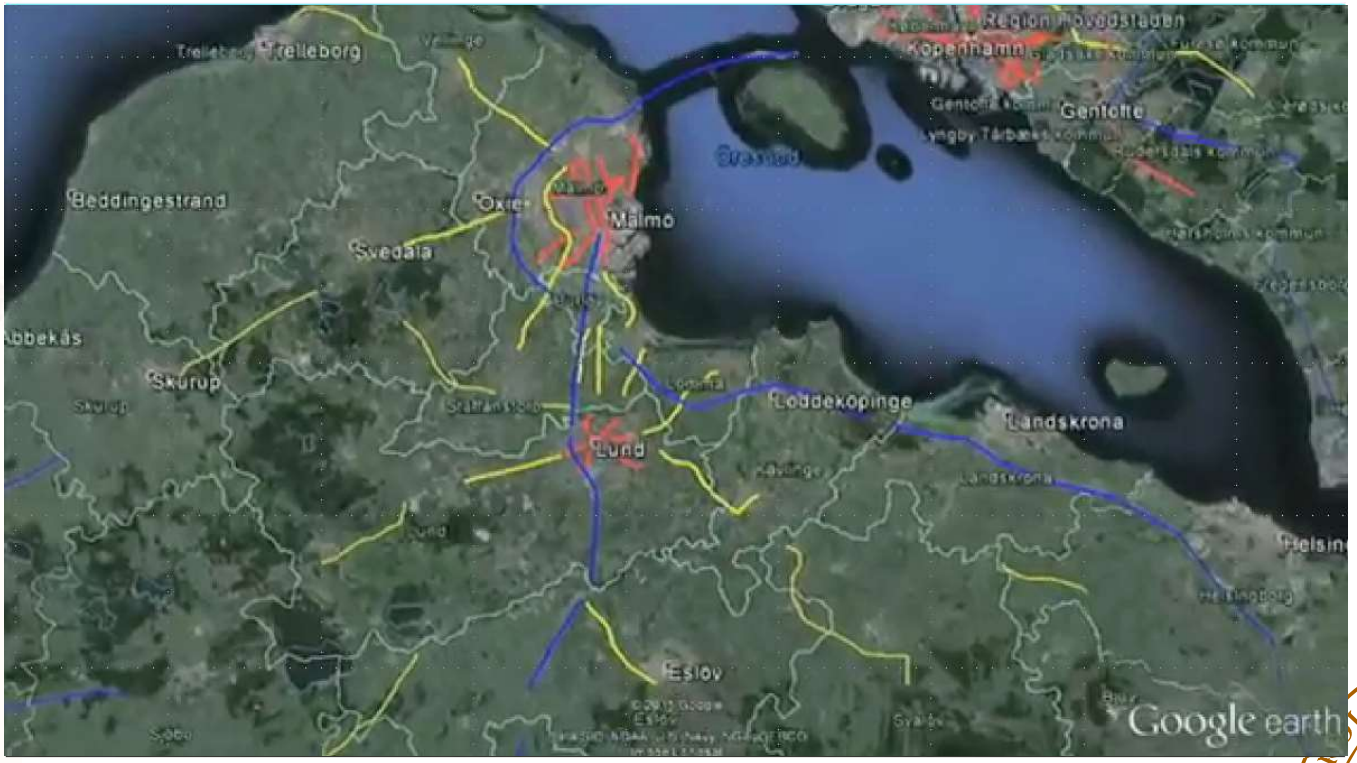


Remember: - ERS reduce the need for batteries to 1/5th

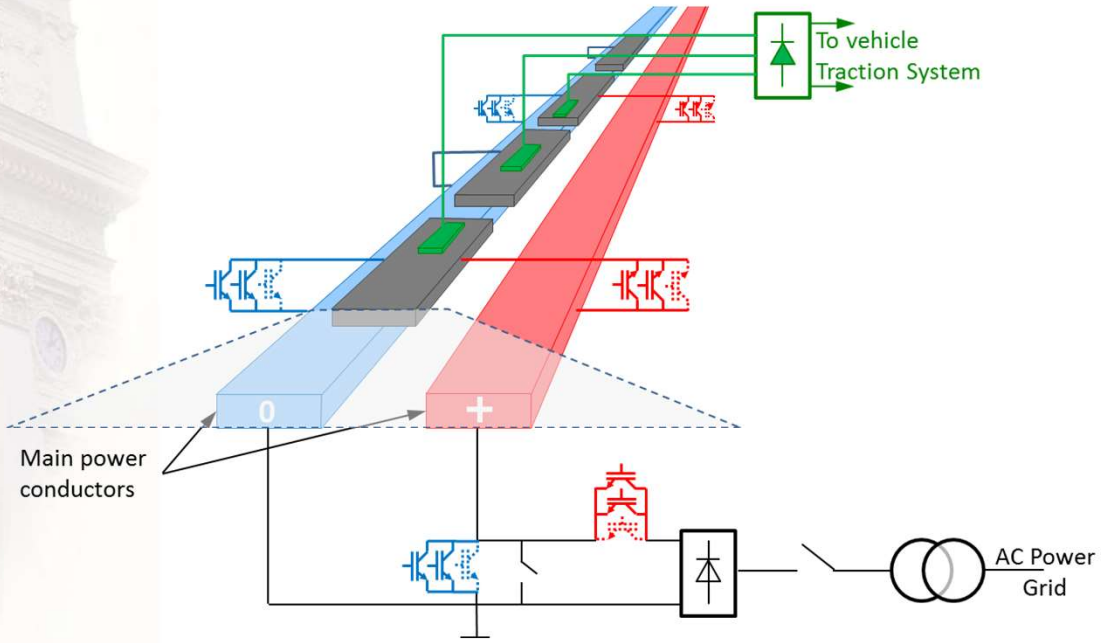
*” 100 km instead of 500 km ”*


Siemens
ELECTRIC
Elonroad
-80 % battery size !
Elways
Elonroad
B
A
Alstom/Volvo
19.26

# Vision of one technology supplier ...



# A technology example...





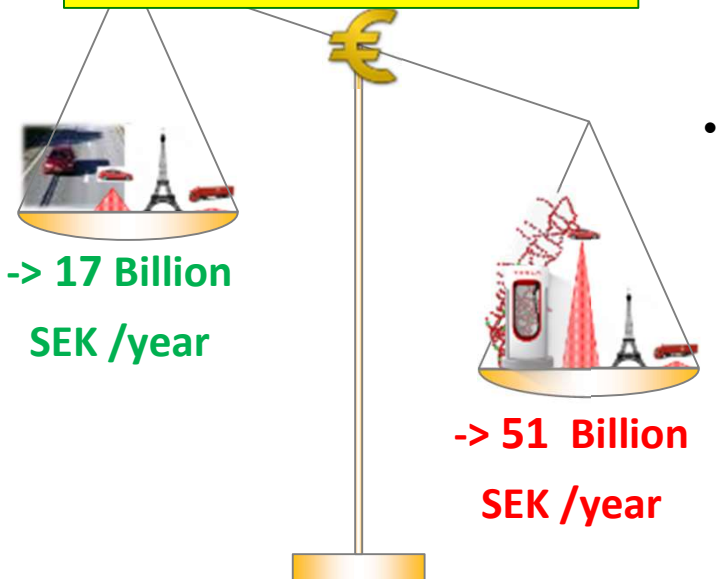
ELONROAD

# Cost of Charging

# Some cost analysis

- 5 million **cars** á **15 kWh** batteries á 1000 SEK/kWh @ 10 years lifetime
  *-> 7 Billion SEK/year*
- 50 000 **Heavy Duty Trucks** á **100 kWh** batteries á 1000 SEK/kWh @ 2 years lifetime
  *-> 2 Billion SEK/year*
- 15 600 km National and European road á 10 Million SEK/km @ 20 years lifetime
  *-> 8 Billion SEK/year*

- Bränsle i transportsektorn: c:a 90 TWh = 9e9 liter = 45 Milliarder SEK exkl skatter !
- Motsvarande El = 30 TWh = 30 Milliarder SEK exkl skatter !
- Skillnad = 15 milliarder SEK !



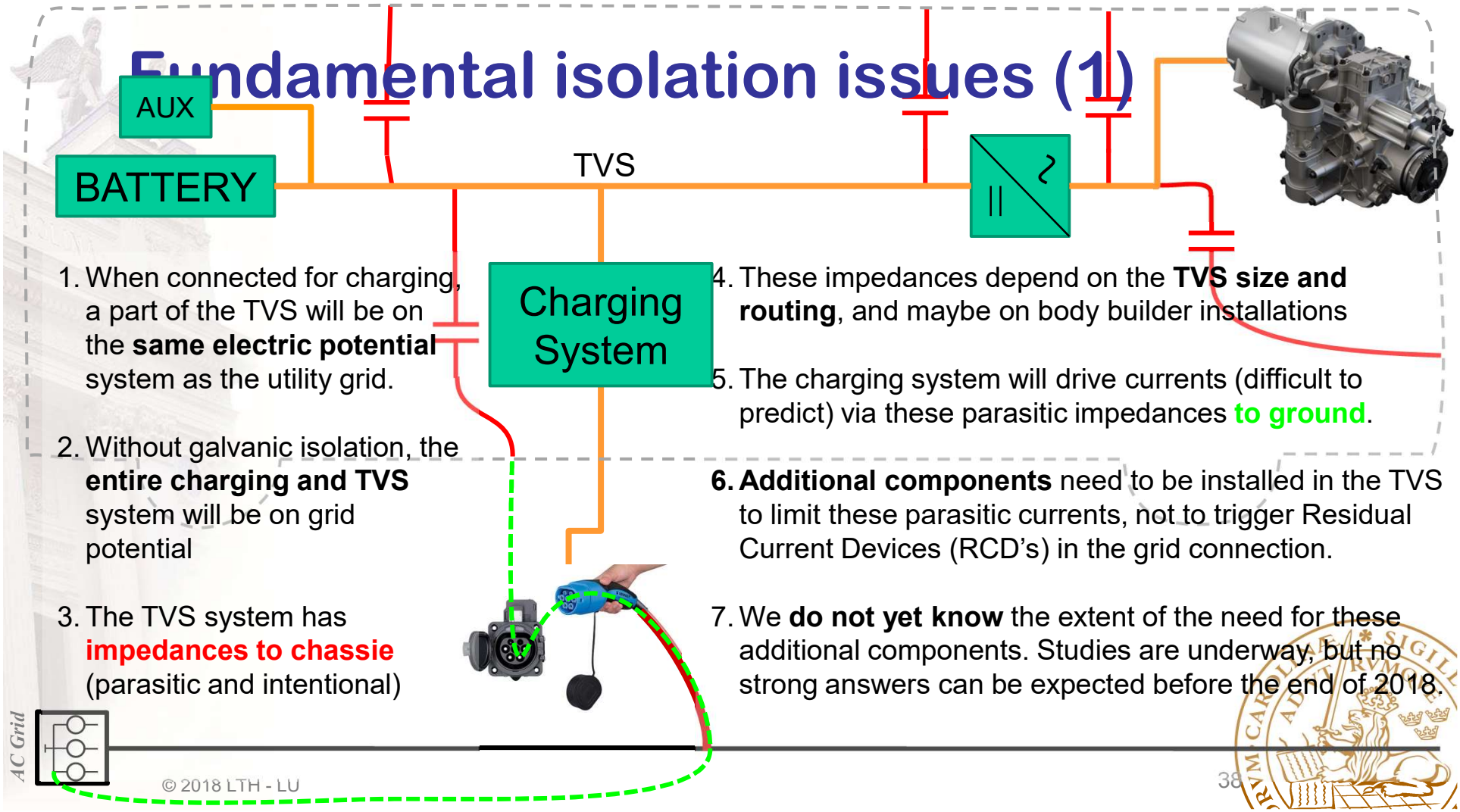
**-> 17 Billion SEK /year**

**-> 51 Billion SEK /year**

- 5 million **cars á 75 kWh** batteries á 1000 SEK/kWh @ 10 years lifetime
  *-> 38 Billion SEK/year*
- 50 000 **Heavy Duty Trucks á 500 kWh** batteries á 1000 SEK/kWh @ 2 years lifetime
  *-> 12 Billion SEK/year*
- 50 000 ”**Super**Chargers” á 150 kW á 6000 SEK/kW @ 25 years lifetime
  *-> 1 Billion SEK/year*
- 500 ”**MEGA**Chargers” á 1000 kW á 6000 SEK/kW @ 25 years lifetime
  *-> 0,12 Billion SEK/year*

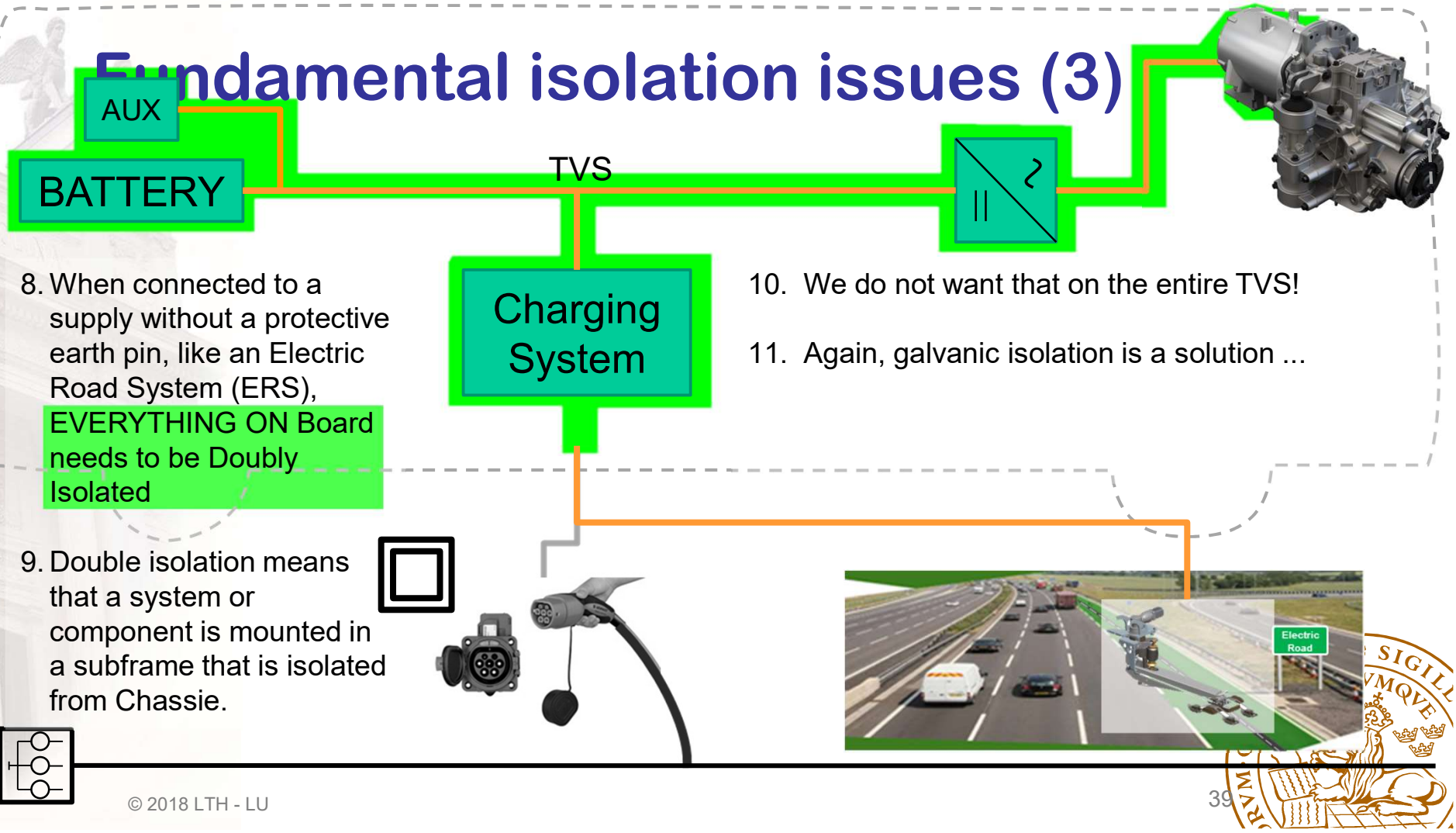
# Principles for galvanic isolation, double isolation and integration

# Fundamental isolation issues (1)




1. When connected for charging, a part of the TVS will be on the **same electric potential** system as the utility grid.
2. Without galvanic isolation, the **entire charging and TVS** system will be on grid potential
3. The TVS system has **impedances to chassie** (parasitic and intentional)
4. These impedances depend on the **TVS size and routing**, and maybe on body builder installations
5. The charging system will drive currents (difficult to predict) via these parasitic impedances **to ground**.
6. **Additional components** need to be installed in the TVS to limit these parasitic currents, not to trigger Residual Current Devices (RCD's) in the grid connection.
7. We **do not yet know** the extent of the need for these additional components. Studies are underway, but no strong answers can be expected before the end of 2018.

# Fundamental isolation issues (3)




8. When connected to a supply without a protective earth pin, like an Electric Road System (ERS), EVERYTHING ON Board needs to be Doubly Isolated

9. Double isolation means that a system or component is mounted in a subframe that is isolated from Chassie.

10. We do not want that on the entire TVS!

11. Again, galvanic isolation is a solution ...

# Fundamental isolation issues (4)

AUX

BATTERY

Charging

System

12. With galvanic isolation in the power supply, only the parts on grid potential need double isolation

13. Any issues with **parasitic impedances** to chassie are predictable and contained

14. Thus - Galvanic isolation ...

a) *... contains the parasitic impedance issues to a predictable and consitent level*

b) *... eliminates need for double isolation of the whole TVS in ERS applications*


AC Grid

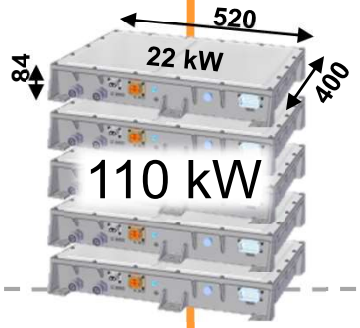
# Applied to AC Charging

# Solutions for galvanic isolation with AC Charging (1

AUX

BATTERY

1. ON board chargers are always galvanically isolated.
2. We can use some of them, like in this example 5x22 kW = 110 kW
3. Weight: 100 kg
4. Size: 520x400x420




PEC

5. That is with one traction machine

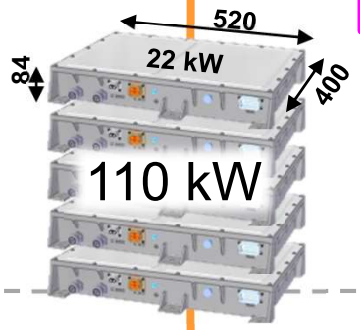
AC Grid

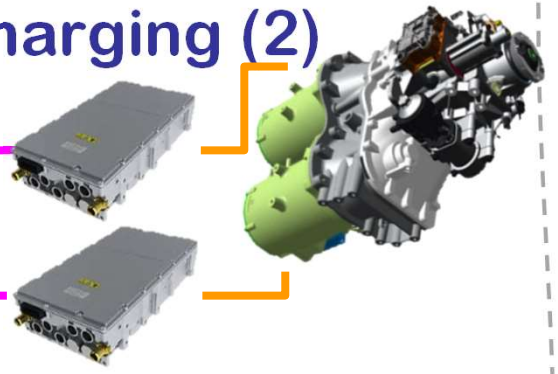
# Solutions for galvanic isolation with AC Charging (2)

AUX

BATTERY

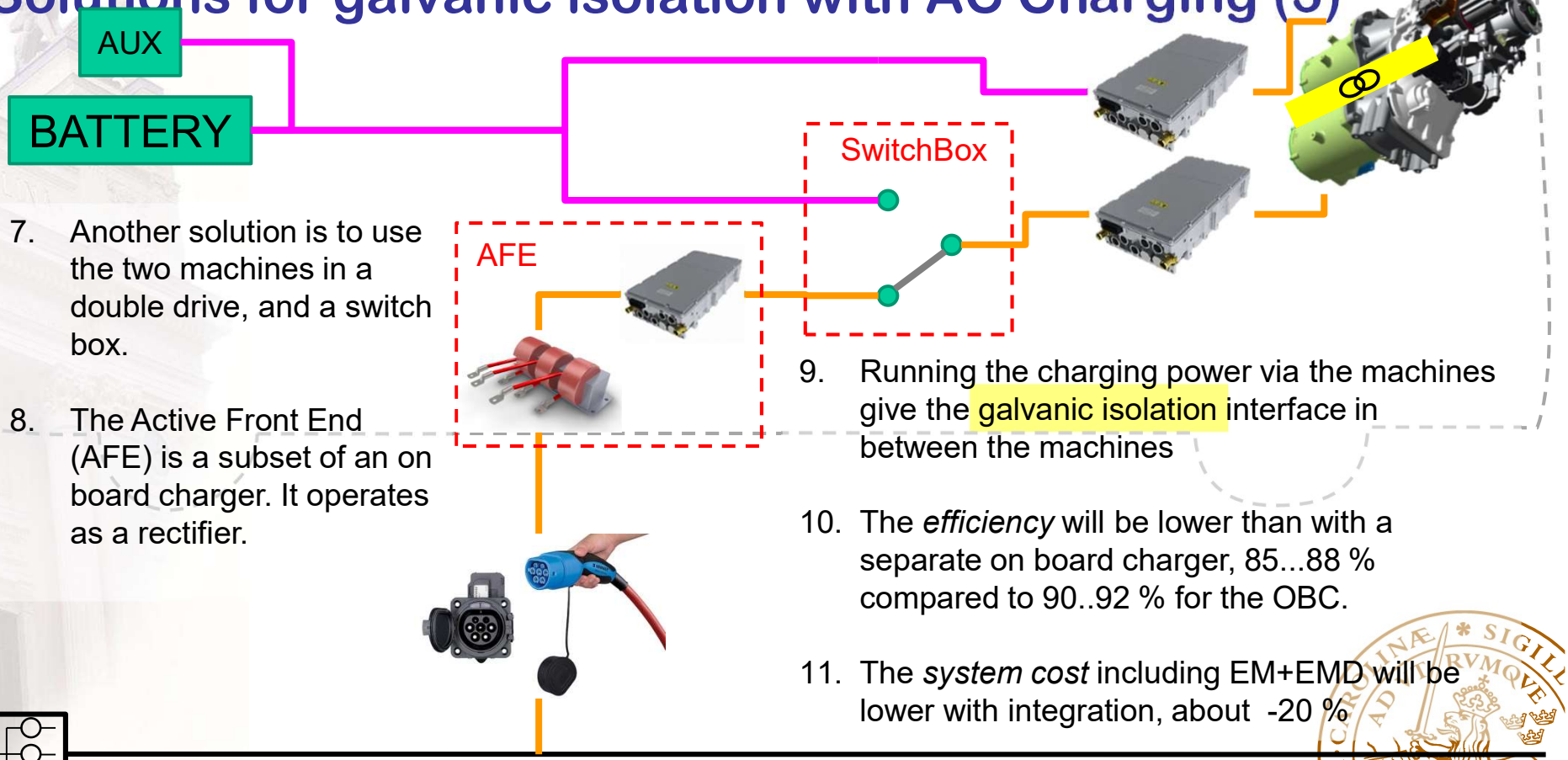
6. It can also be done with two traction machines



AC Grid

# Solutions for galvanic isolation with AC Charging (3)




7. Another solution is to use the two machines in a double drive, and a switch box.

8. The Active Front End (AFE) is a subset of an on board charger. It operates as a rectifier.

9. Running the charging power via the machines give the galvanic isolation interface in between the machines

10. The *efficiency* will be lower than with a separate on board charger, 85...88 % compared to 90..92 % for the OBC.

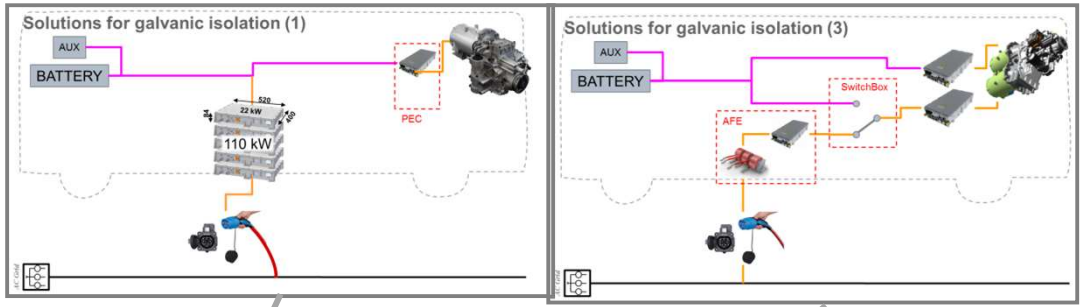
11. The *system cost* including EM+EMD will be lower with integration, about -20 %

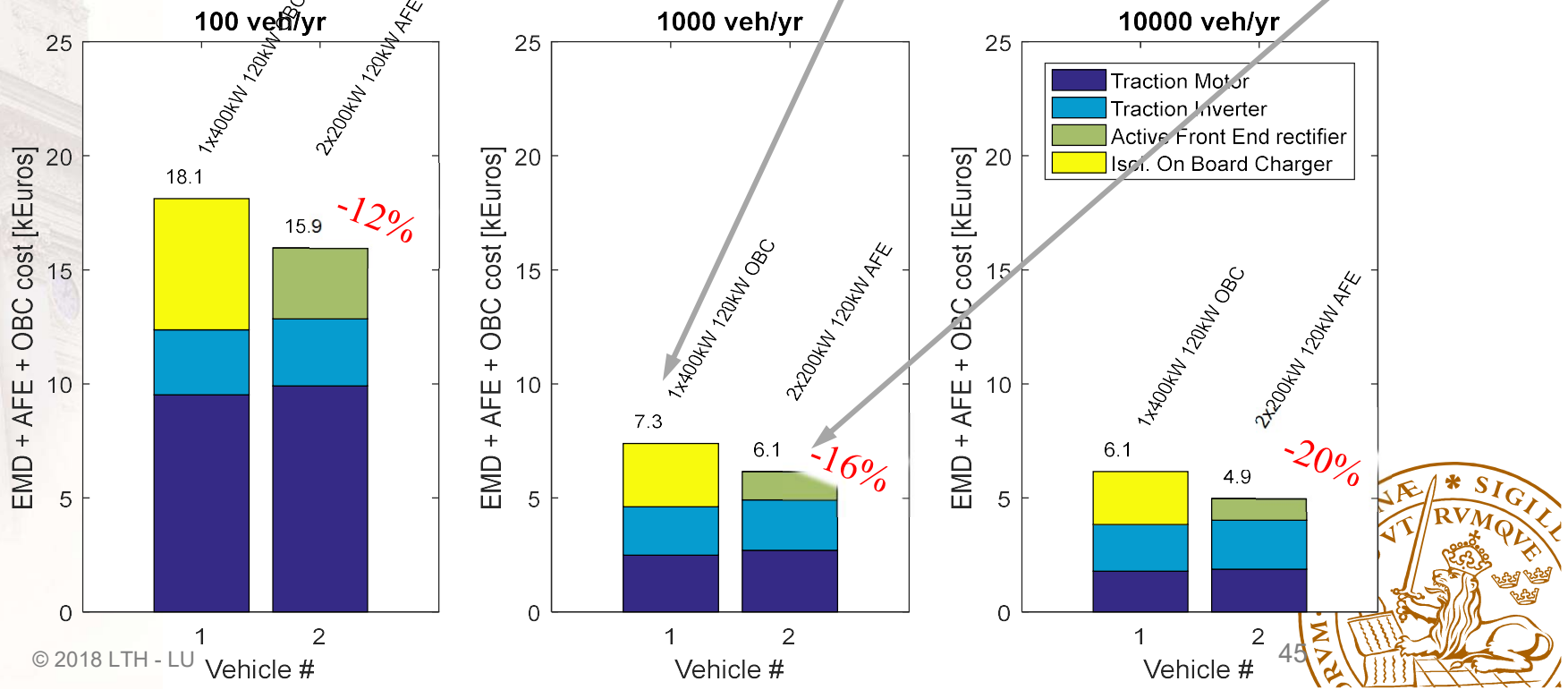
# System Cost AC Charging

1 x 240/400 kW Cont/Peak + 110 kW OBC

*OR*

2 x 120/200 kW Cont/Peak



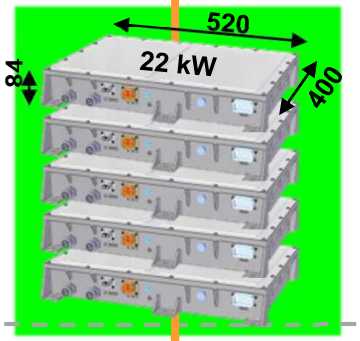



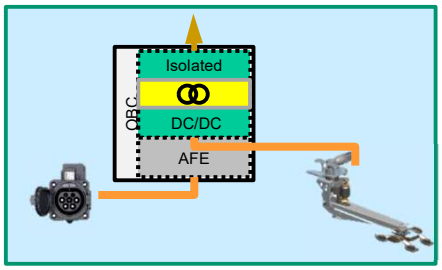
# Including ERS Charging

# Including AC and ERS charging compatibility (1)

AUX

BATTERY



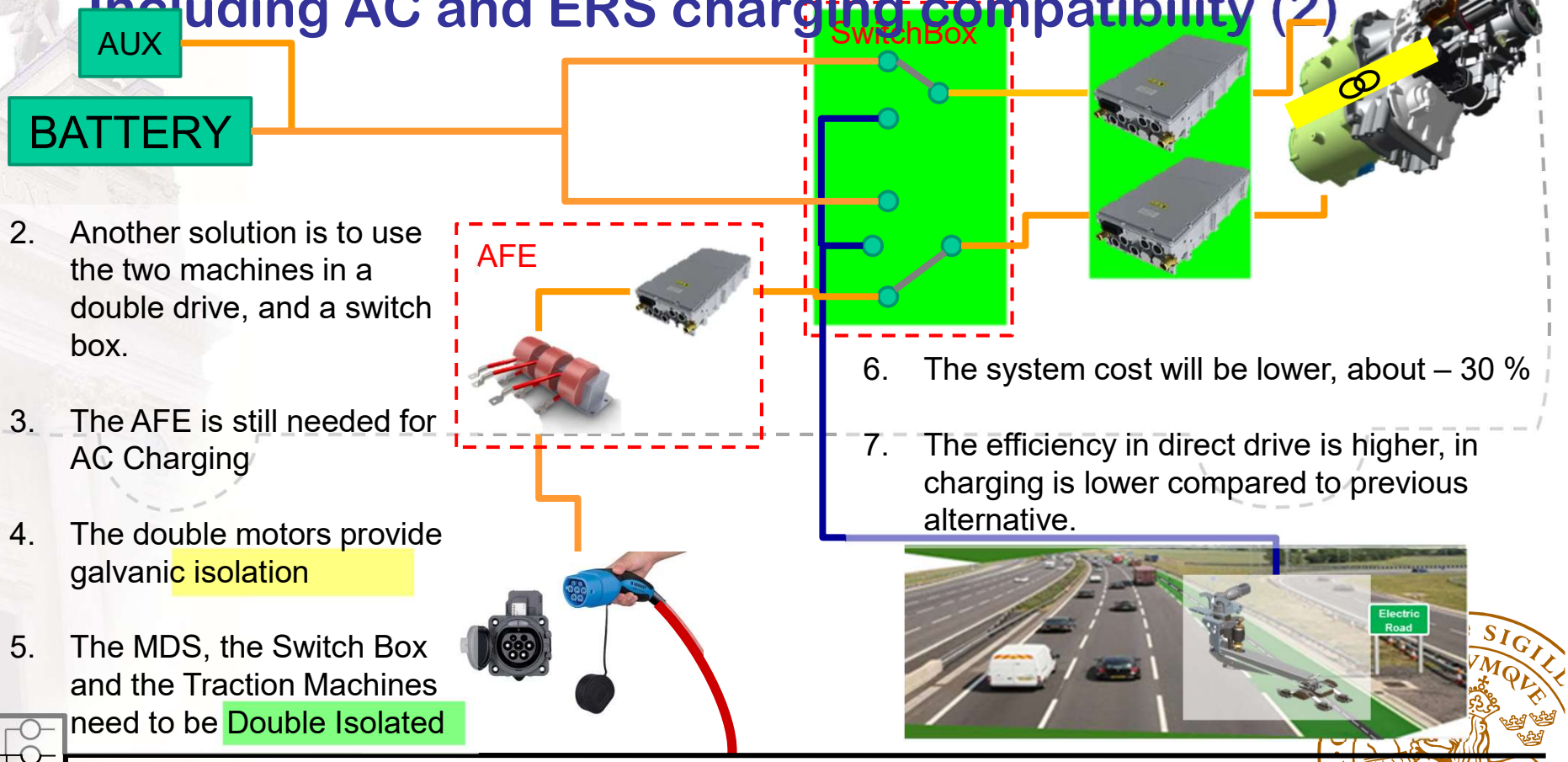




1. The OBC contains the galvanically isolated DC/DC that ERS needs, and only double isolation needs to be added

2. The OBC consists of an Active Front End Converter and an Isolated DC/DC converter


AC Grid

# Including AC and ERS charging compatibility (2)




2. Another solution is to use the two machines in a double drive, and a switch box.

3. The AFE is still needed for AC Charging

4. The double motors provide galvanic isolation

5. The MDS, the Switch Box and the Traction Machines need to be Double Isolated

6. The system cost will be lower, about – 30 %

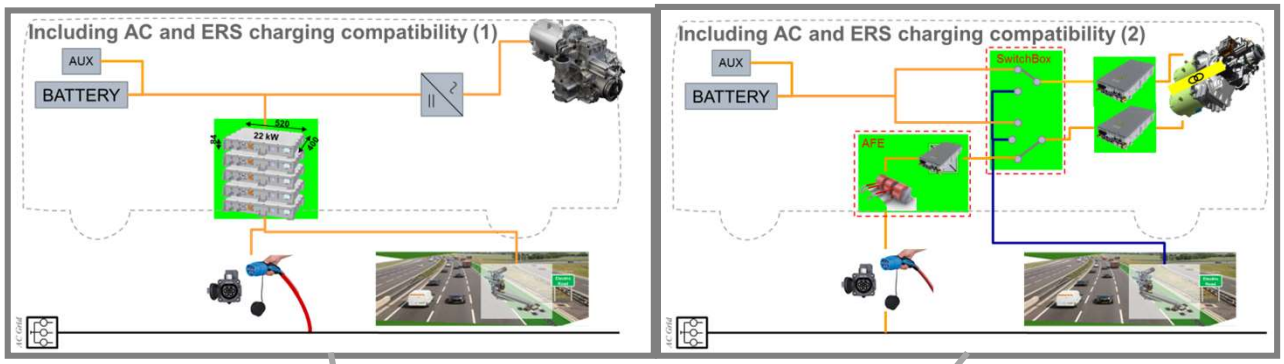
7. The efficiency in direct drive is higher, in charging is lower compared to previous alternative.

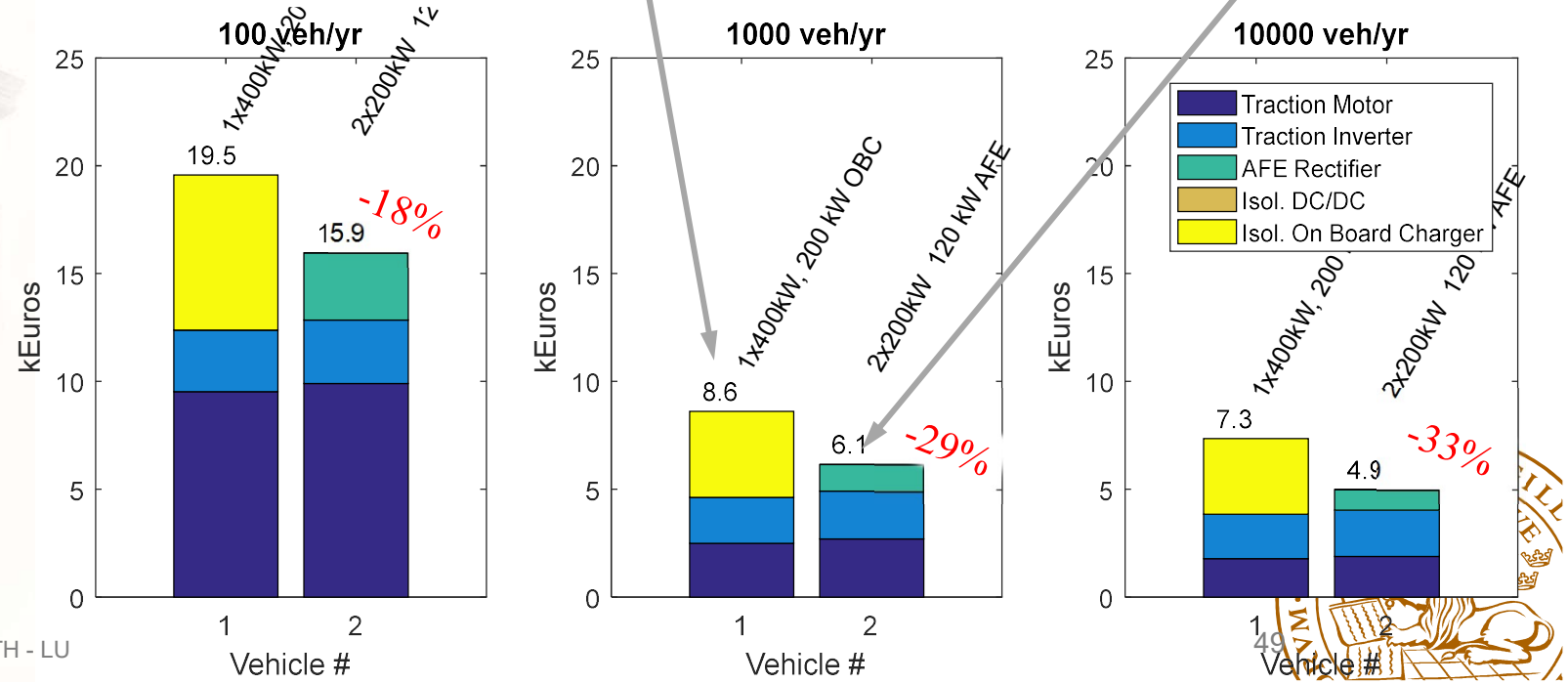



AC Grid

# AC+ERS System Cost

1 x 240/400 kW Cont/Peak + 200 kW OBC
*OR*
2 x 120/200 kW Cont/Peak + 120 kW AFE

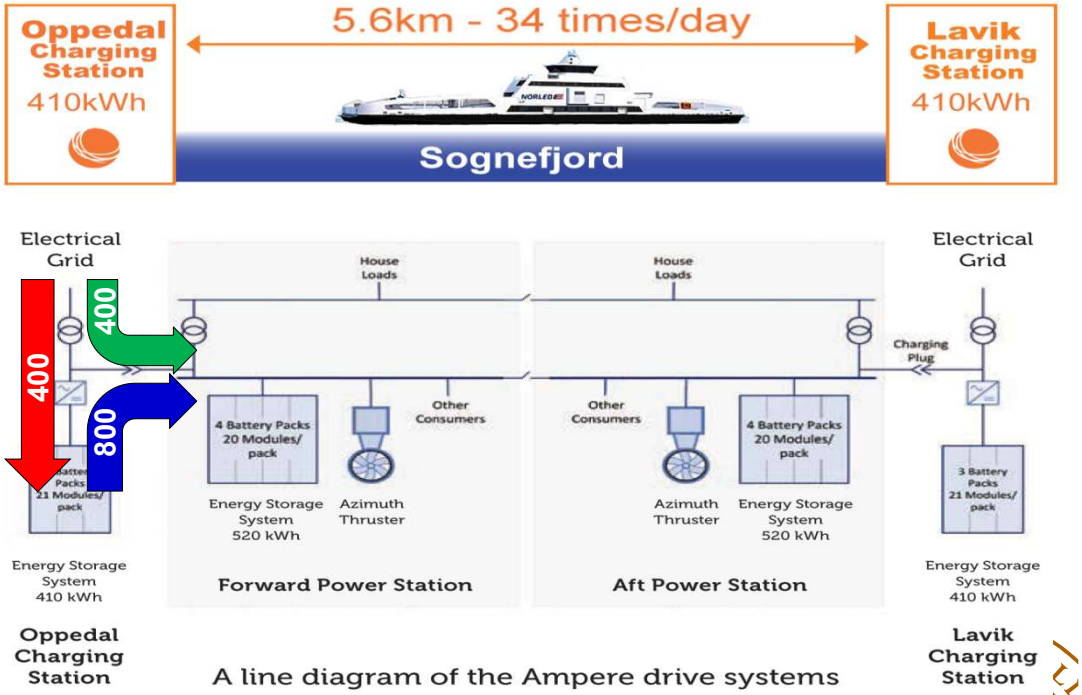


# Can all this be used off road?

# How to Provide a Big Ferry with Full Electric Drive !

- 10 min Dock / 20 min Transport
- Boat Battery:
  - 1040 kWh, 20 tons, 50 Wh/kg
  - 200 kWh / trip (20% DoD)
    - 34 times a day
    - Assume 100 k Cycles
    - 2900 days = 8 years
  - Charge at 1200 kW in 10 minutes (C=1.2)
- Shore Battery:
  - 410 kWh
  - Charge @ 400 kW in 20 min (C=1,0)
    - 133 kWh/cycle, 32 % DoD
    - Assume 30 k Cycles
    - 1800 days = 5 years
  - Discharge @ 800 kW in 10 min (C=2,0)
  - PLUS Grid @ 400 kW for 10 min !



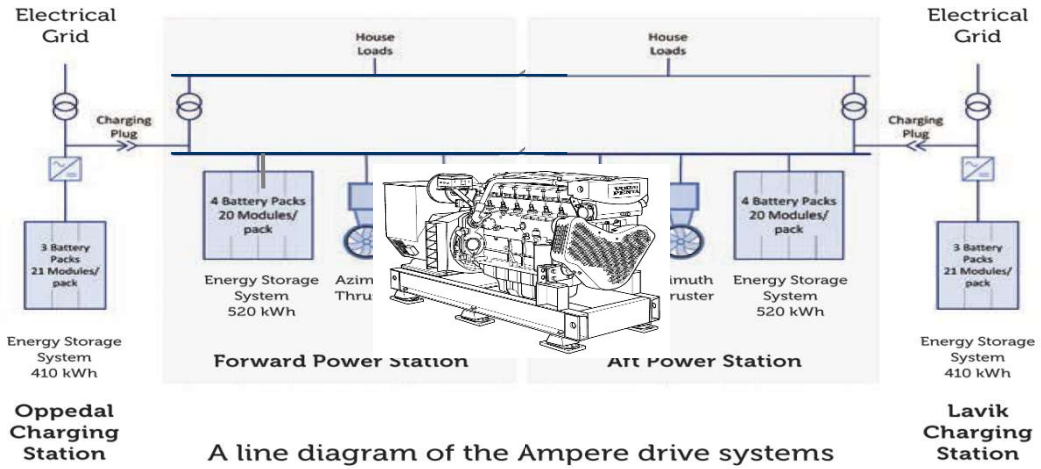

A line diagram of the Ampere drive systems

# What if the trip was longer ?

- **Bigger battery + more charging?**
- **”Pain limit” reached?**
- **Fill in with HYBRID !**

- **Here, a Series Hybrid!**

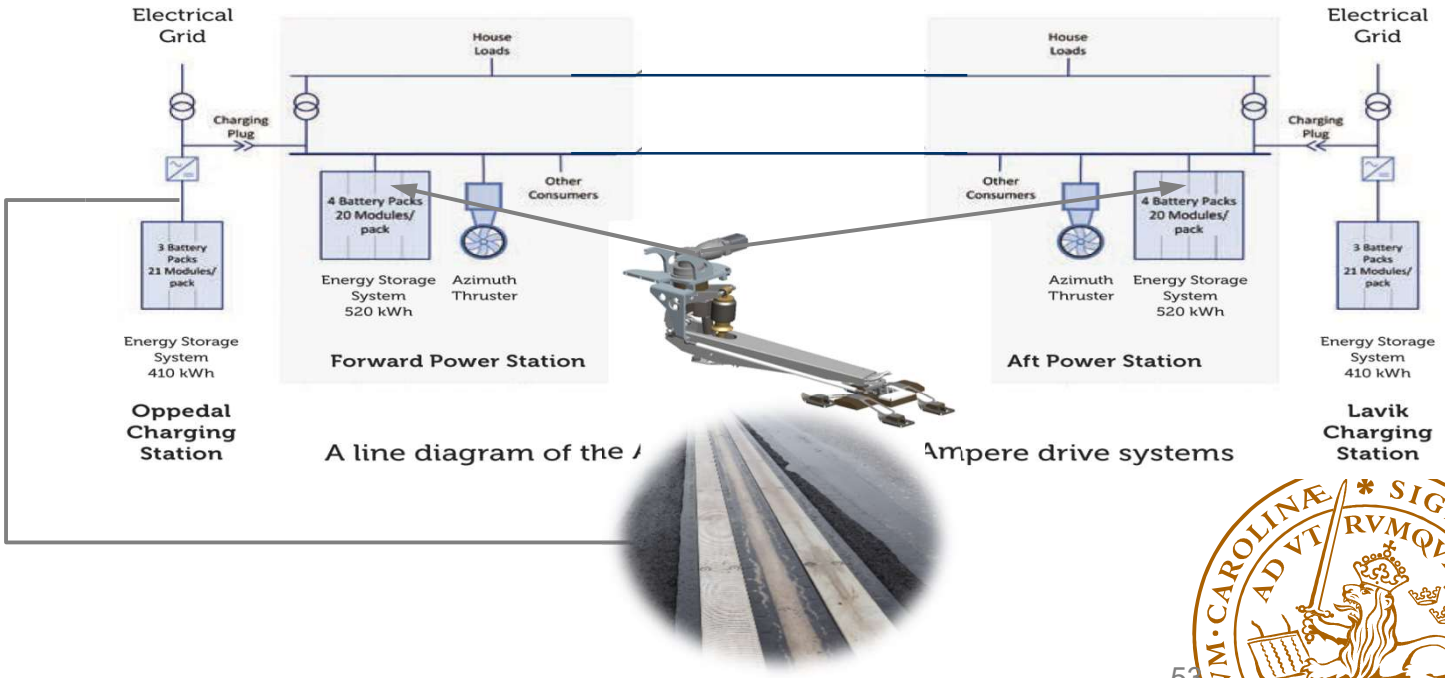
- **Can also be a Parallel Hybrid!**
  - Combustion engine drive directly on the Thruster
  - Use our Hybrid Drive for Buses?




A line diagram of the Ampere drive systems

# And what if it was on land?

- **No Hybrid Needed!**
- **Use Dynamic Charging to ”fill in”**



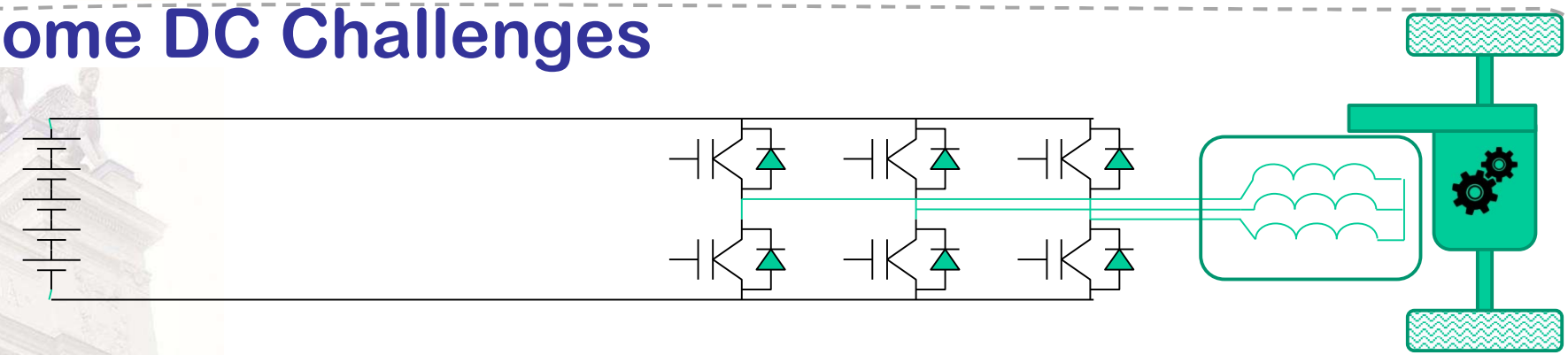
# Current Loading





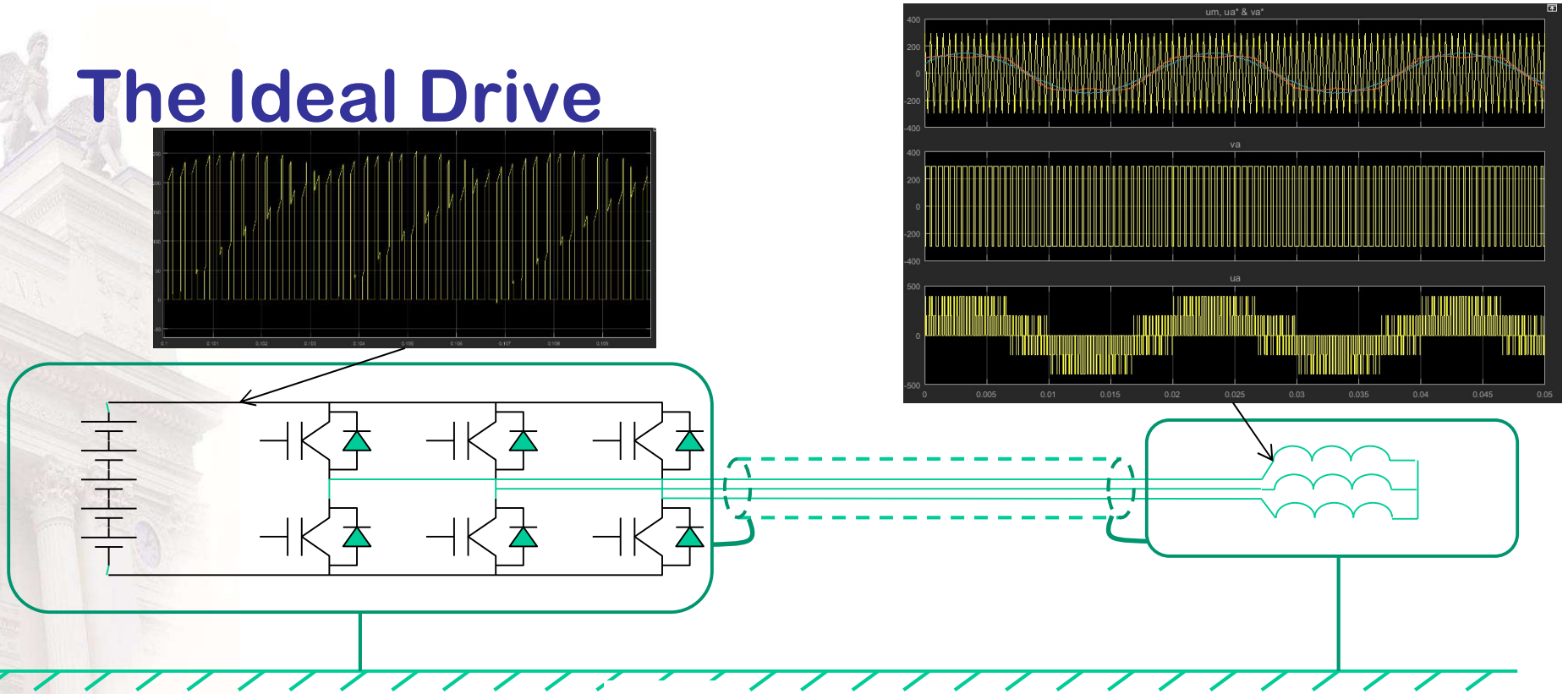
# Charging Solutions

# Some DC Challenges

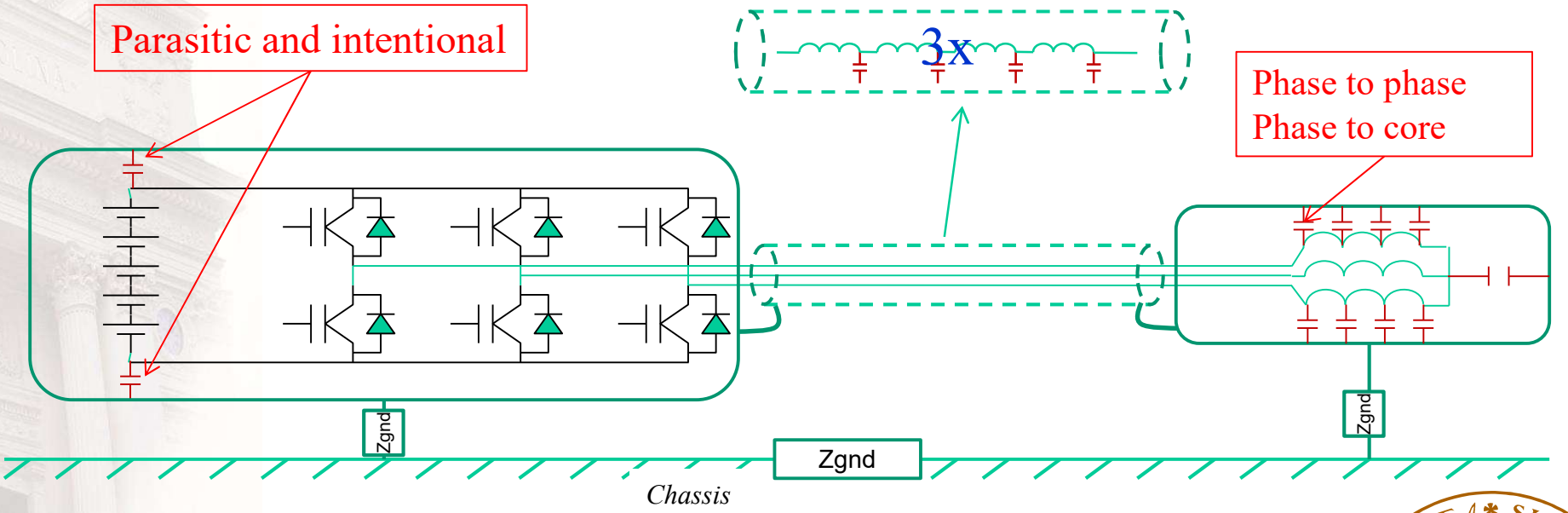


- Identify Isolations faults (Battery to Chassis)
- Limit the DC link current ripple

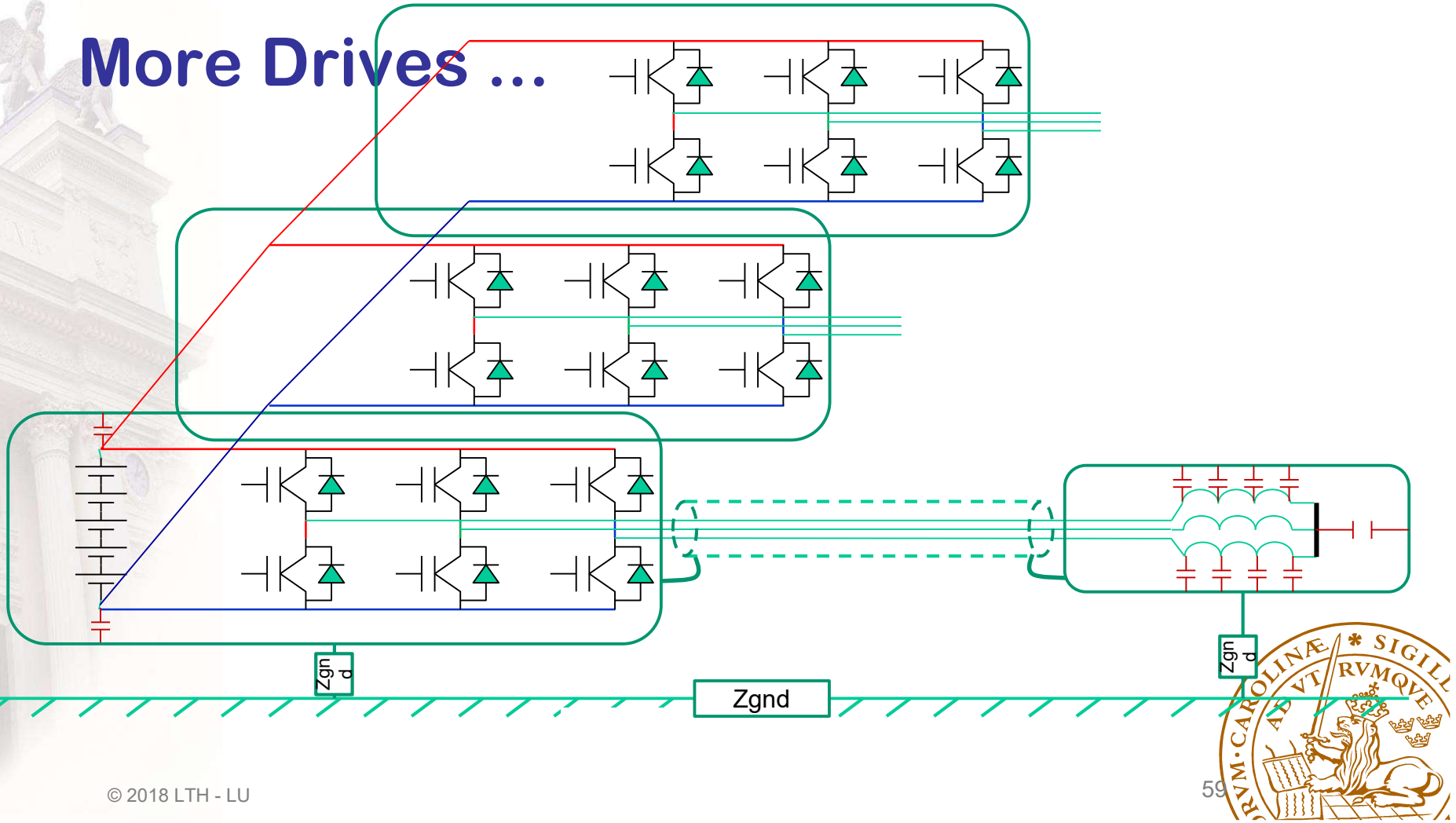
# The Ideal Drive



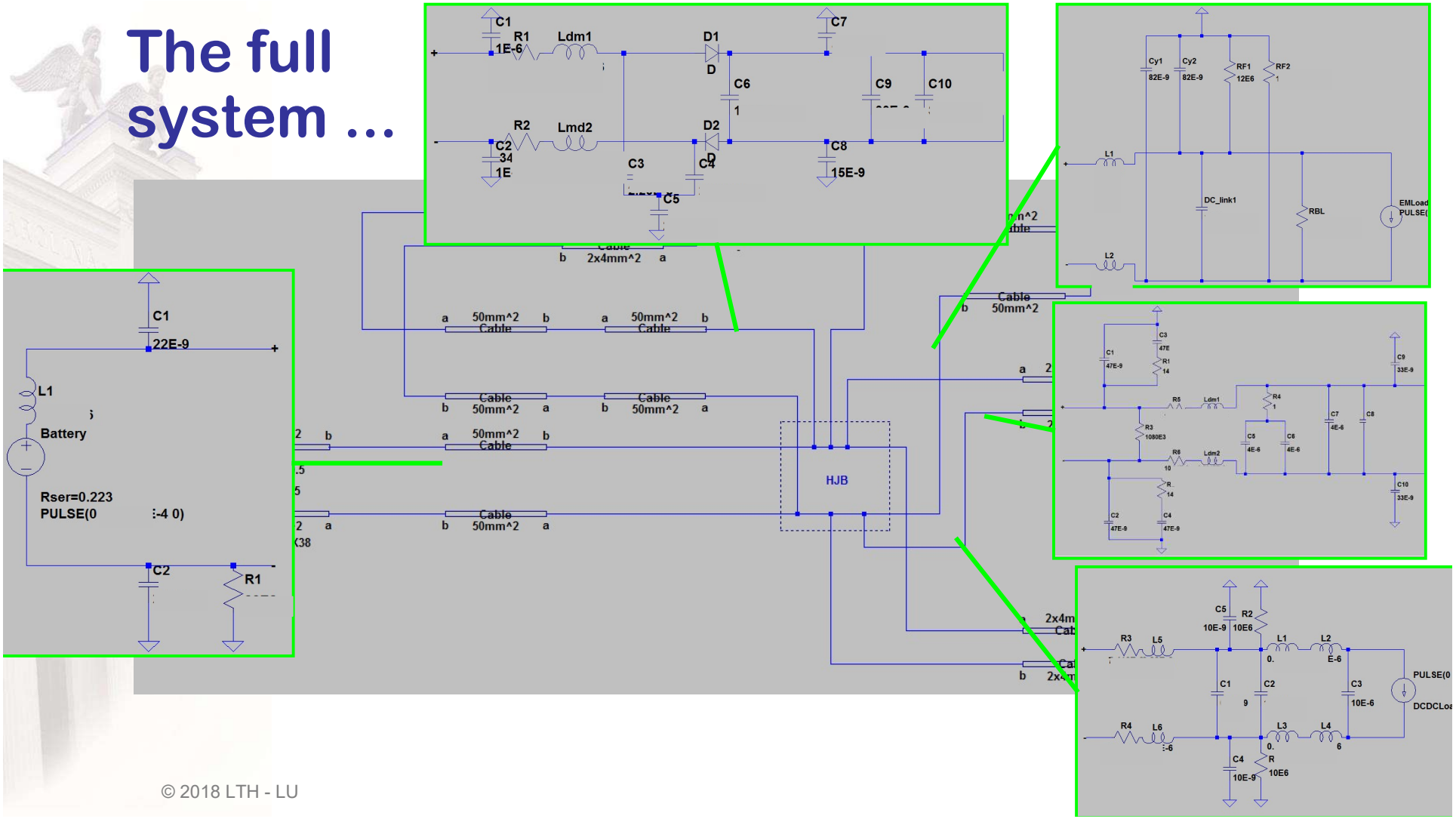
# Some parasitics ++

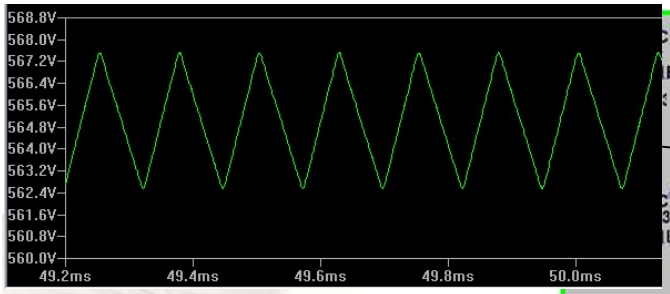


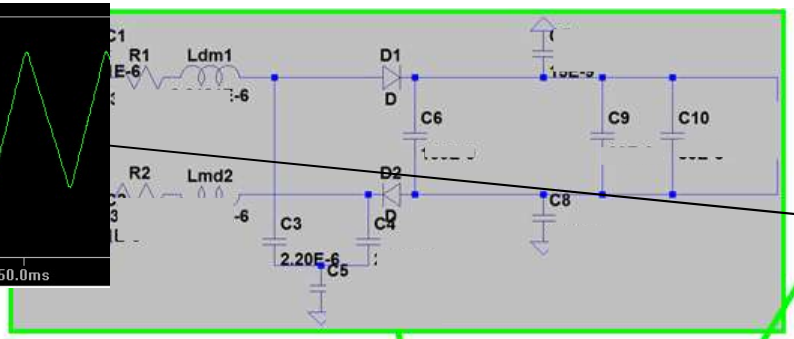
# More Drives ...

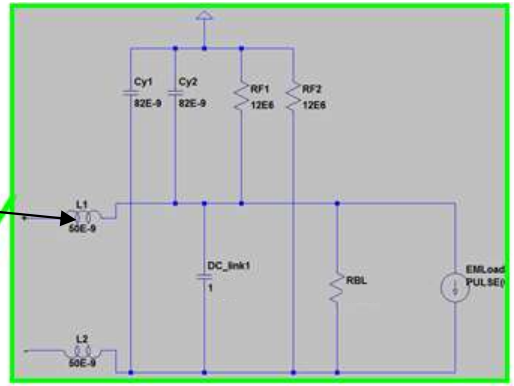


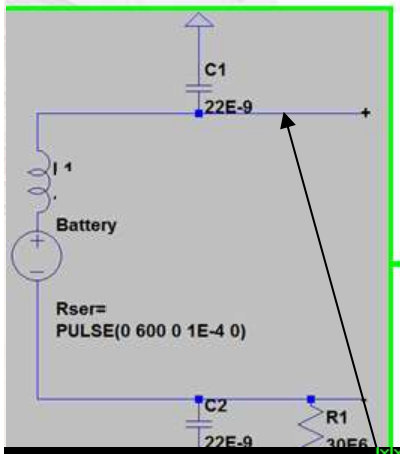
# The full system ...





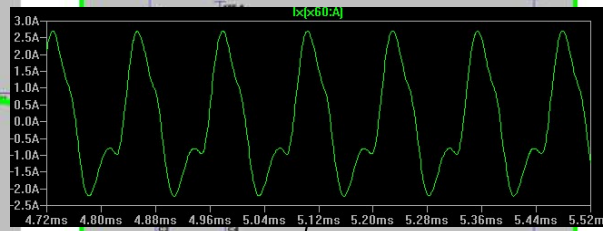



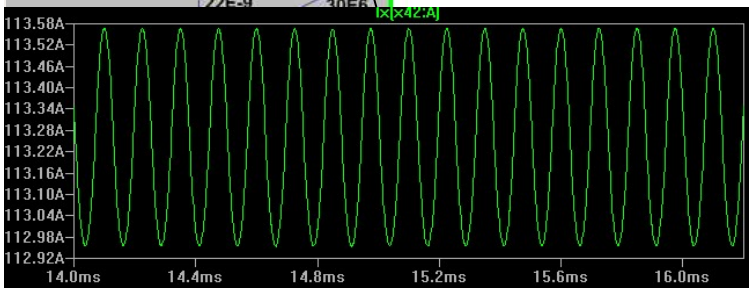

**Some conclusions:**

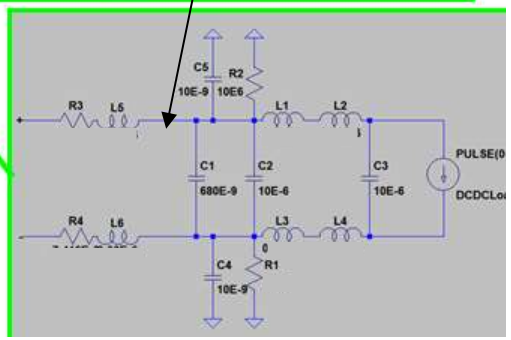
1 A Complex circuit

2 A High Excitation

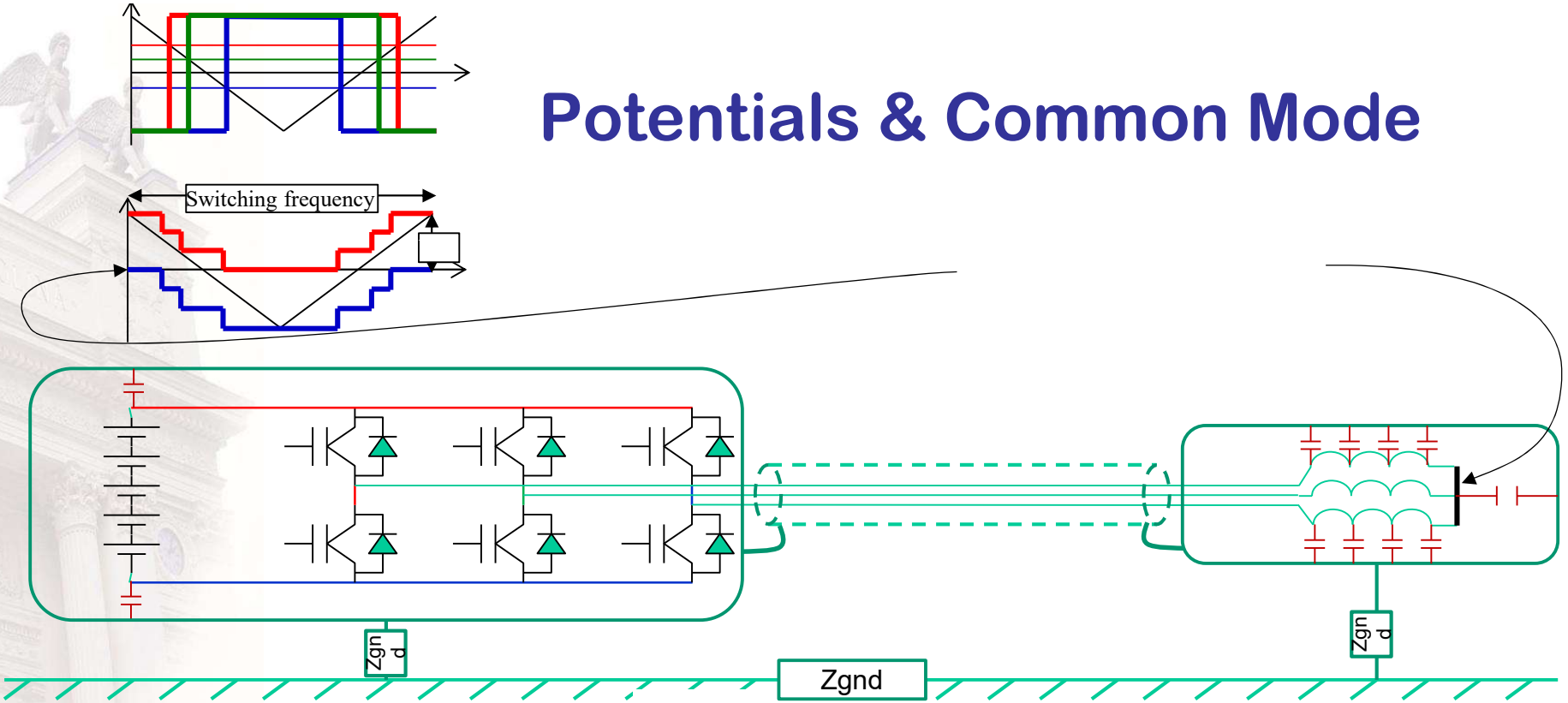
3 Complex harmonics distribution



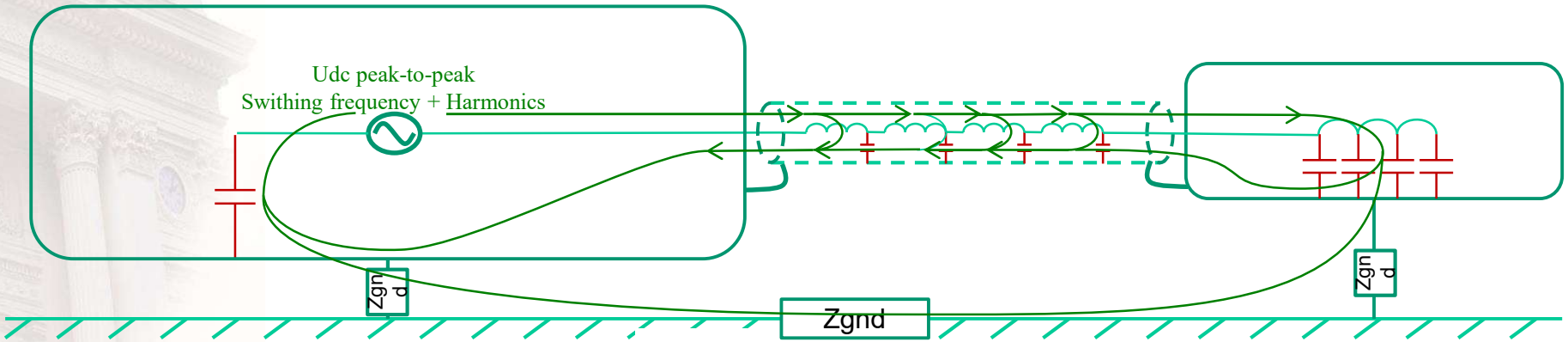



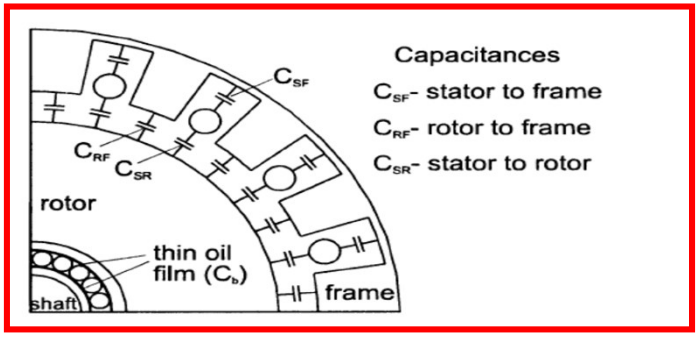
# Potentials & Common Mode

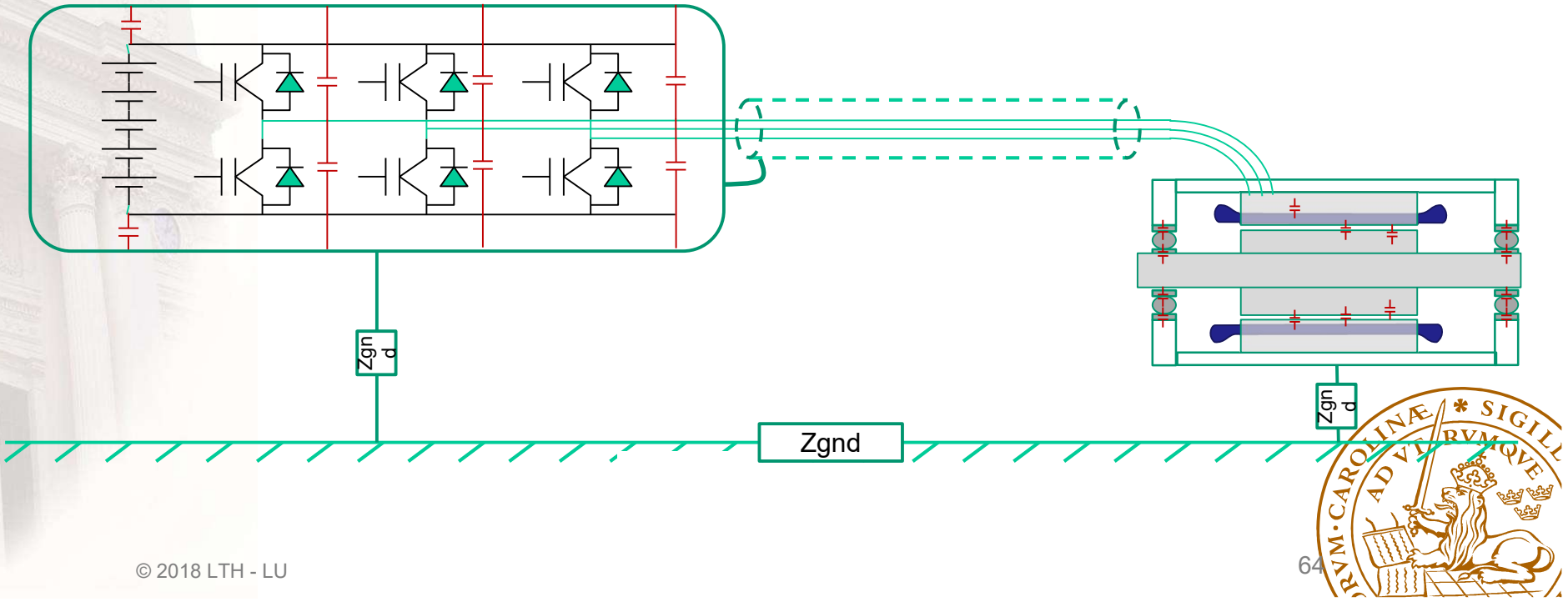


# Equivalent Circuit

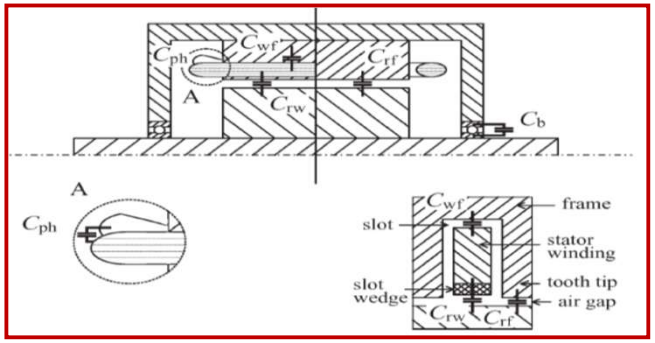


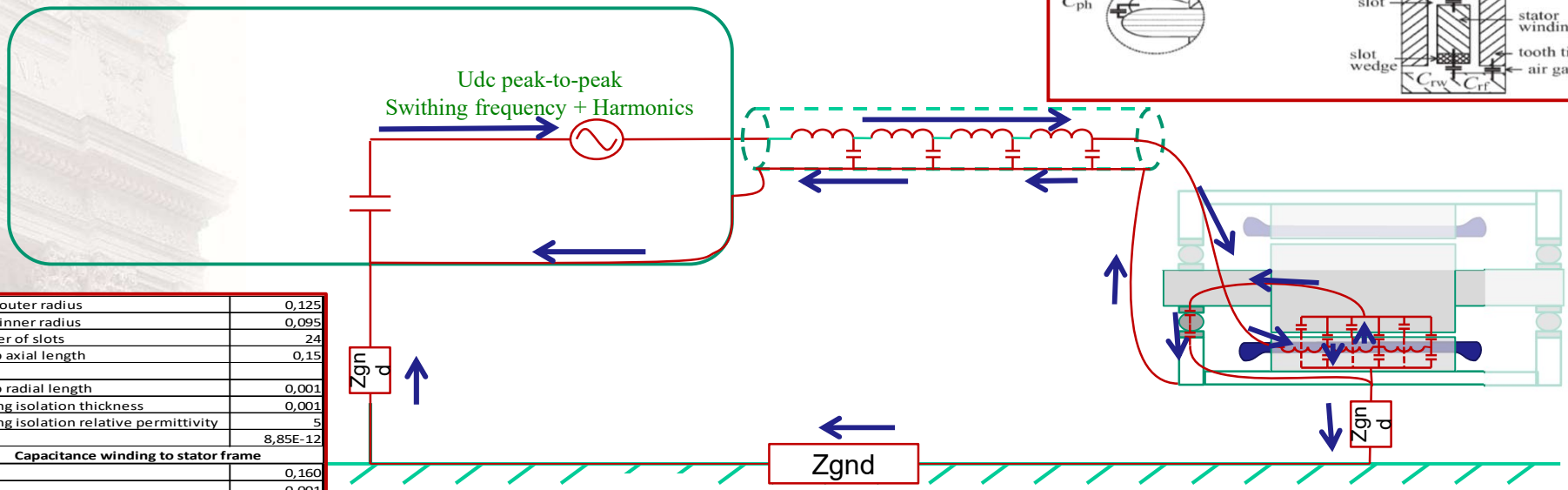
# Some more parasitics +++



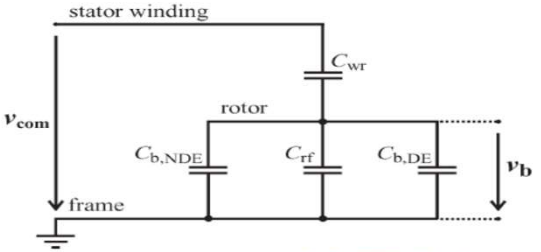
# Equivalent Circuit ++



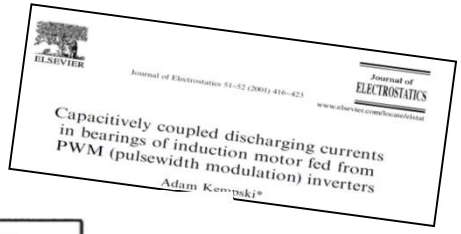




| | |
|---|---|
| Stator outer radius | 0,125 |
| Stator inner radius | 0,095 |
| Number of slots | 24 |
| Air gap axial length | 0,15 |
| | |
| Air gap radial length | 0,001 |
| Winding isolation thickness | 0,001 |
| Winding isolation relative permittivity | 5 |
| e0 | 8,85E-12 |
| **Capacitance winding to stator frame** | |
| A | 0,160 |
| d | 0,001 |
| Cws [pF] | 7 076 |
| **Capacitance winding to rotor** | |
| A | 0,022 |
| d | 0,003 |
| Cwr [pF] | 66 |
| **Capacitance stator stator to rotor** | |
| A | 0,067 |
| d | 0,001 |
| Csr [pF] | 595 |
| | |
| **Bearing Capacitance** | |
| Typical Bearing Capacitance [pF] | 50 000 |

$$\mathrm{BVR} = \frac{v_b}{v_{com}} = \frac{C_{wr}}{C_{wr} + C_{rf} + 2C_b}.$$



# Axial paths



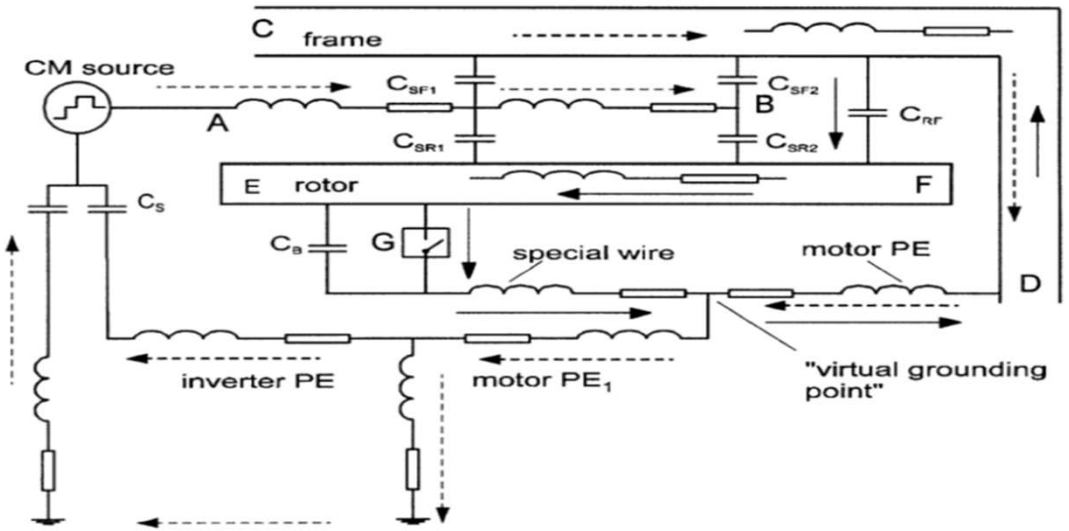
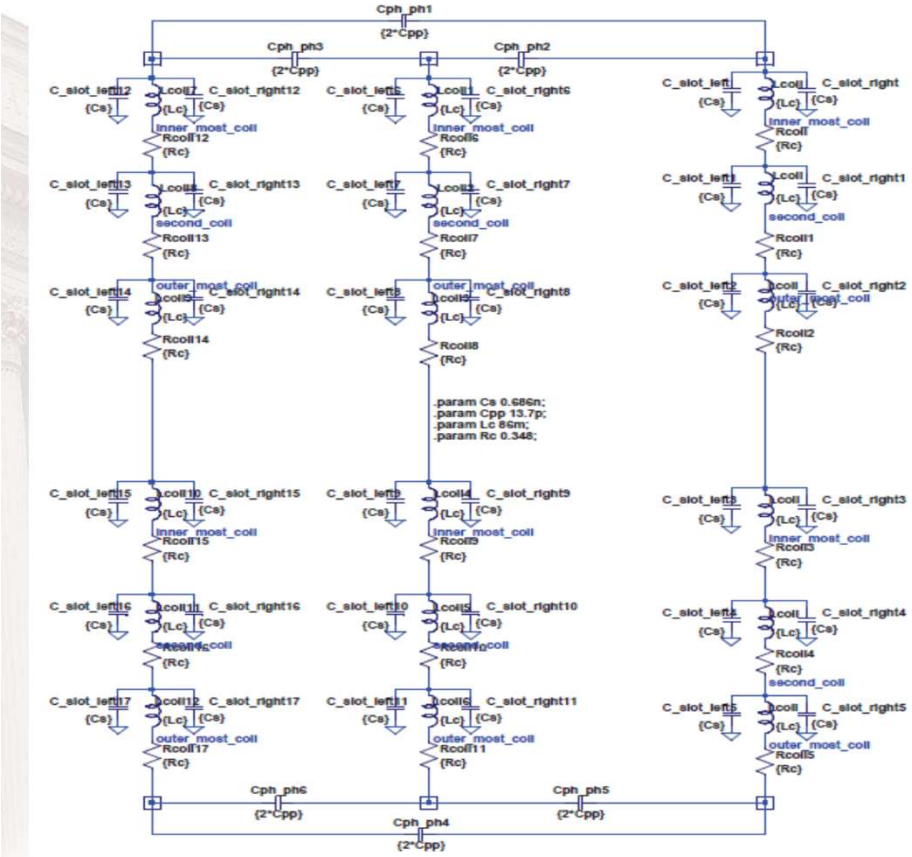
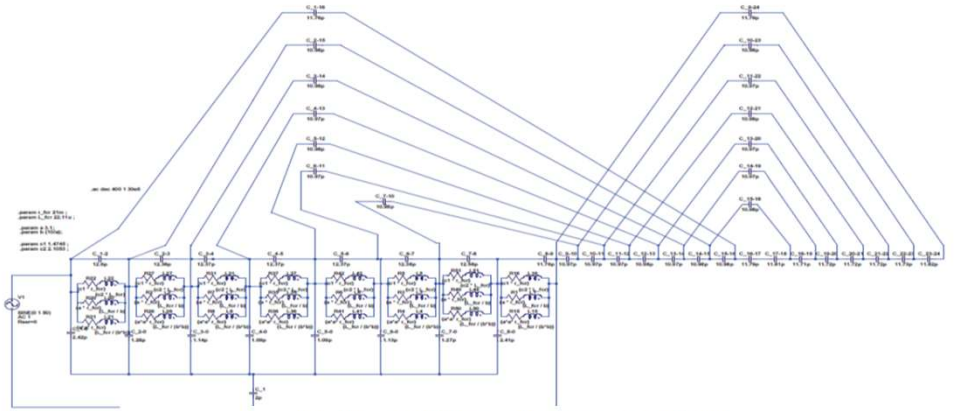
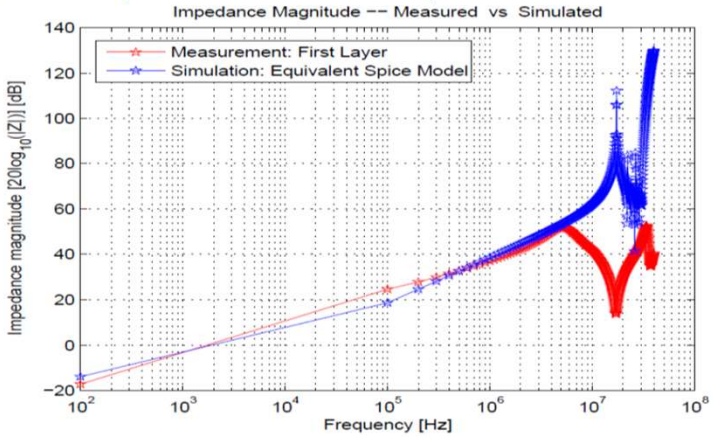




Fig. 8. Common mode equivalent model.

# More details ...

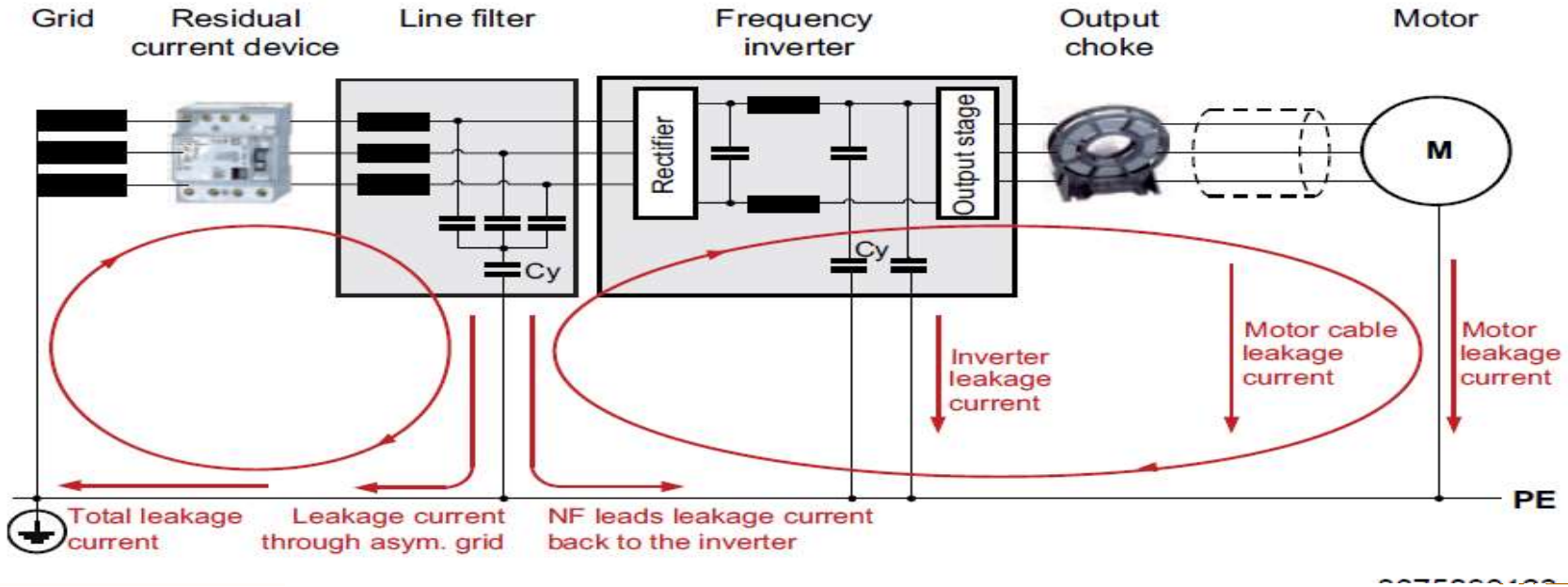


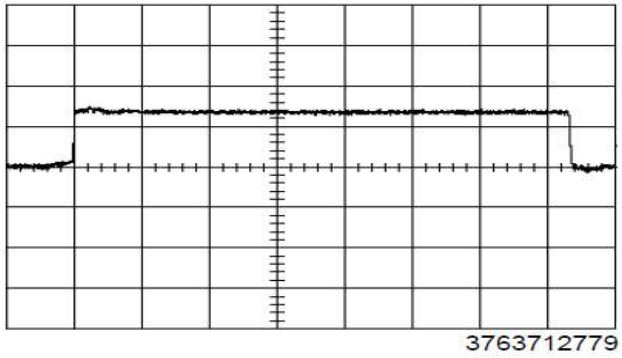


# Leakage current damping


The following figure shows the leakage currents of a controlled drive with suitable EMC measures.



# Motor/Cable Impedance Mismatch Leads to reflection and overvoltage up to 2x

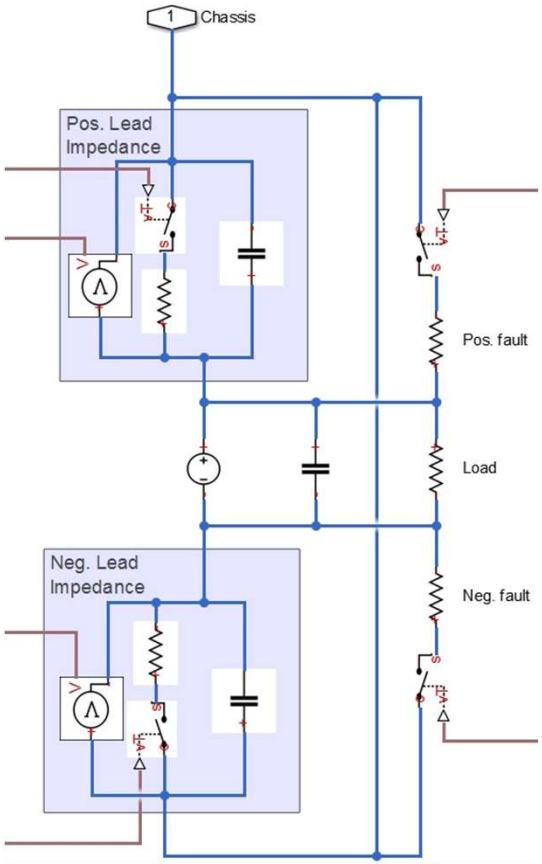



Voltage characteristics
at the output of the frequency inverter

Voltage characteristics
at the motor terminals

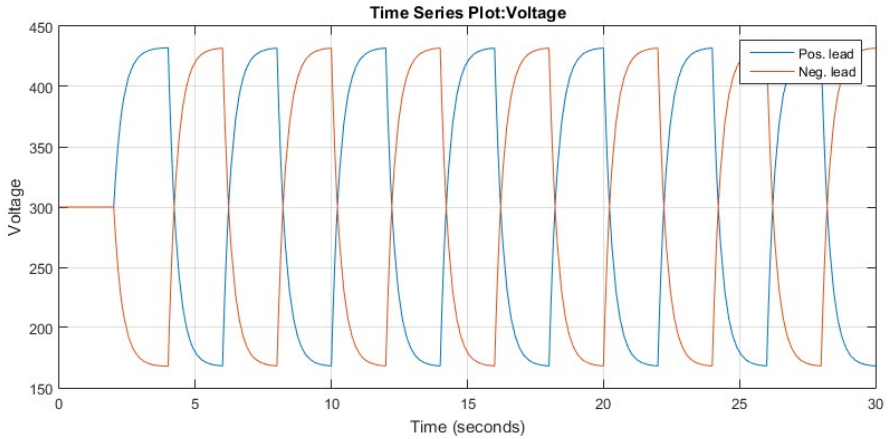
# Floating GND

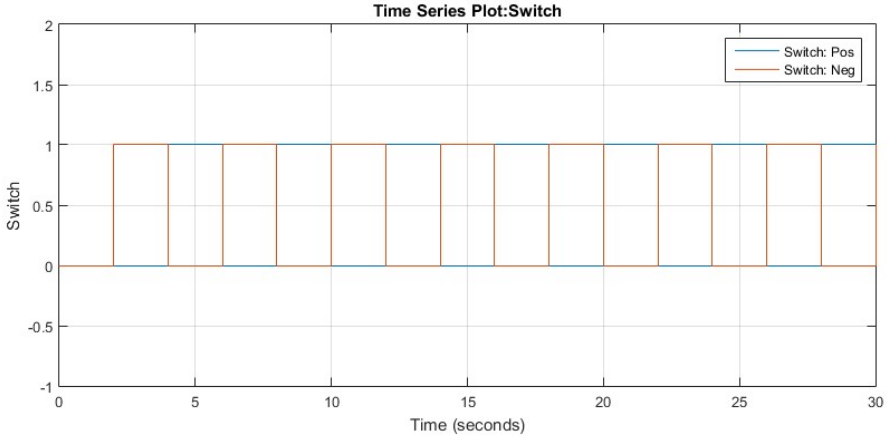
- R @chassis = 375kOhm
- C @chassis = 700nF
- C @line-to-line = 1500microF
- V @battery = 600 V
- Controlled Faults



# Without Faults

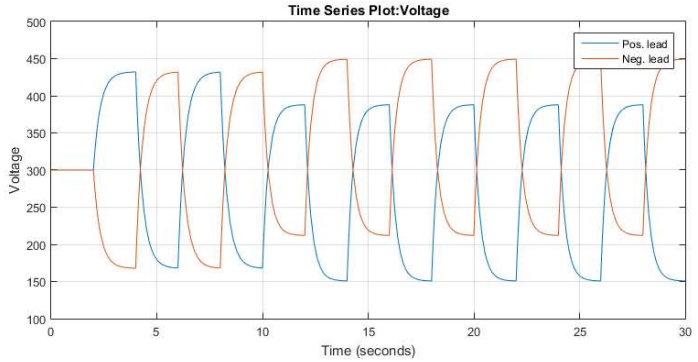
- Switching Time = 2 s
- No Faults
- Voltages ~300±130 V



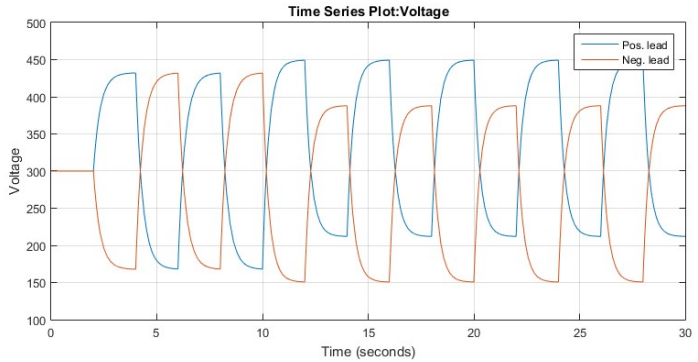



# 1 Mohm isolation faults

- Switching Time = 2 s
- Top
  - Fault @pos. = 1MOhm

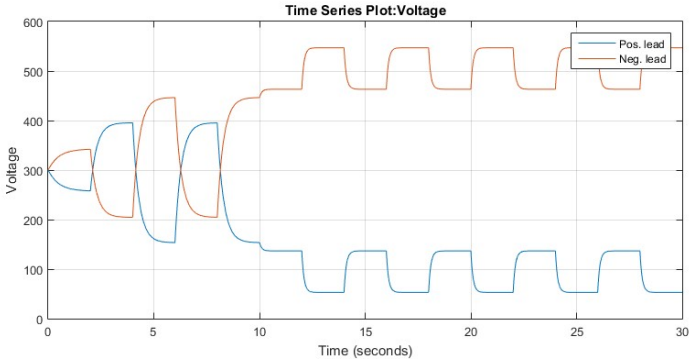



- Bottom
  - Fault @neg. = 1MOhm

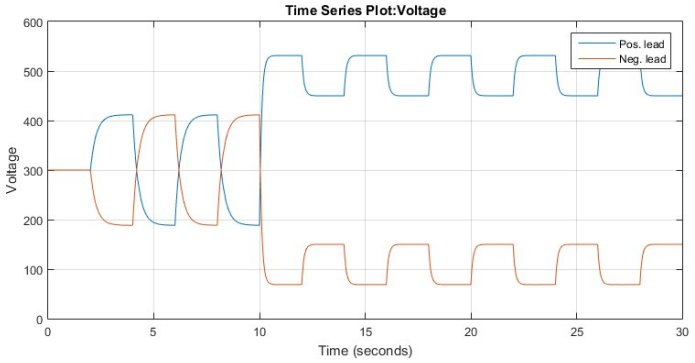


# 100 kOhm faults

- Switching Time = 2 s
- Top
  - Fault @pos. = 100kOhm

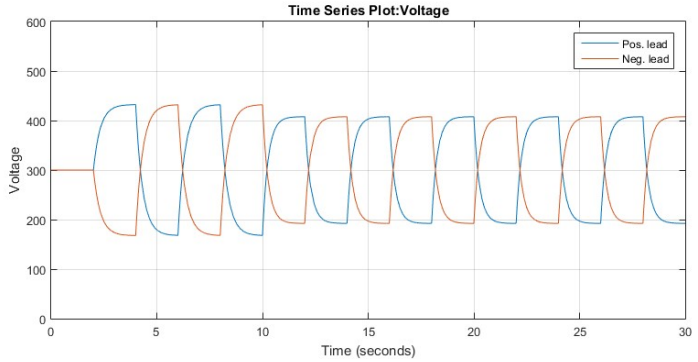


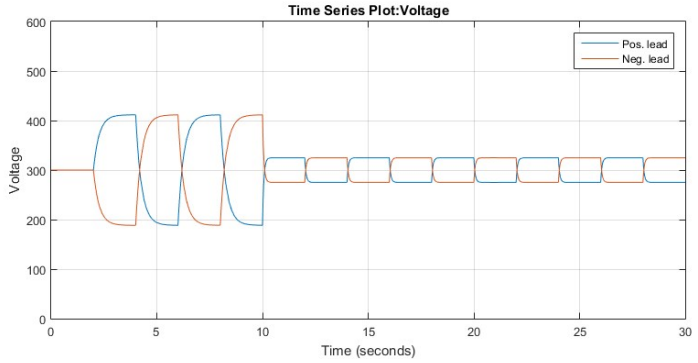

- Bottom
  - Fault @neg. = 100kOhm



# Two different faults

- Switching Time = 2 s
- Top
  - Faults = 1MOhm
- Bottom
  - Faults = 100kOhm



# Conclusions

- The Traction Motor Drive, and almost all other drives connnected to the Traction Battery, draw a Pulsed current from the Battery Circuit.
- The battery Ciruit contains A LOT of reactive components (Capacitors and Inductors)
- The harmonic spectrum from the drives connected to the Traction Battery, spread and interact through on the Traction Voltage System.
- This cause resonances, ageing and even malfunction on systems connected to the Traction Voltage System. A detalied understanding is needed.

- Parasitic components (inductances and capacitances) appear between the battery and the chassis, between the motor windings and the magnetic core of the motors, between power semiconductors and their heatsinks and between the power cables and their shields.
- These parasitics contribute to common mode currents (the same current in both battery cables AND/OR in all three motor cables) that cause ageing of insulation, bearings and possibly malfunction of Earth Fault Protectors (= Residual Current Detectors)
- Intentional impedance variations between the battery circuit and the chassis are used to detect isolations failures.