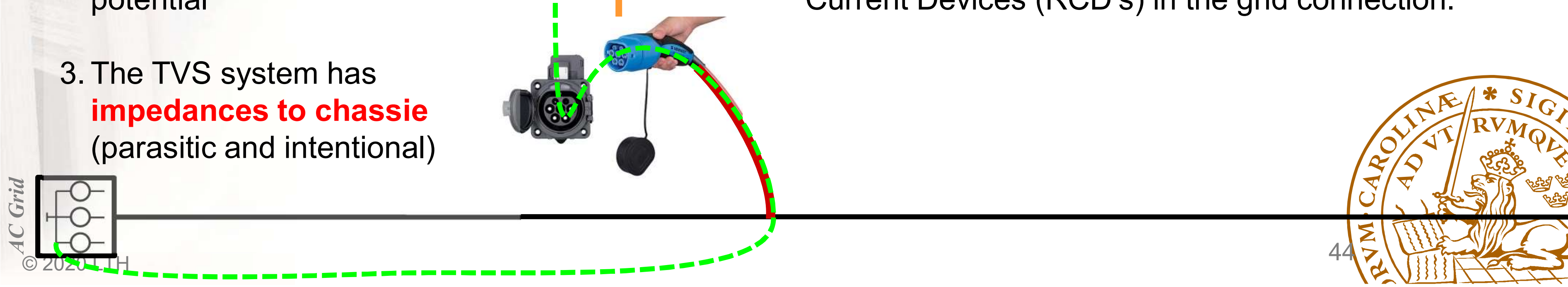
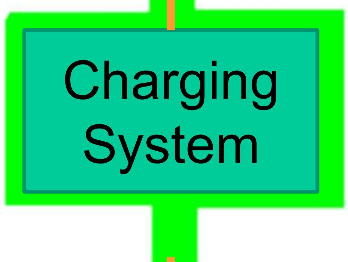
Principles for galvanic isolation, double isolation and integration

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.



Fundamental isolation issues (3)

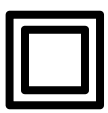


8. When connected to a supply without a protective earth pin, like an Electric Road System (ERS), EVERYTHING ON Board needs to be Doubly Isolated

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

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

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



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*

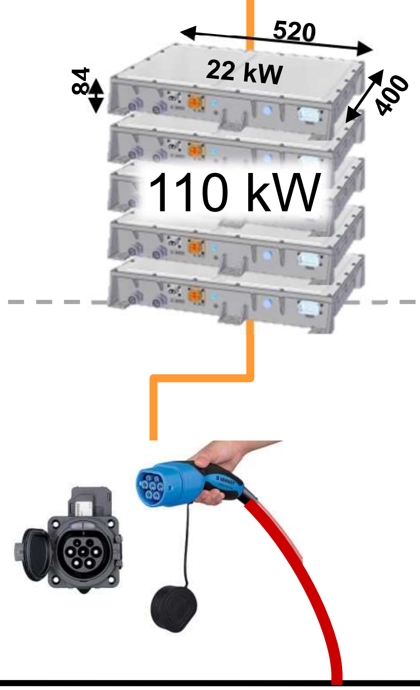
AC Grid

Applied to AC Charging

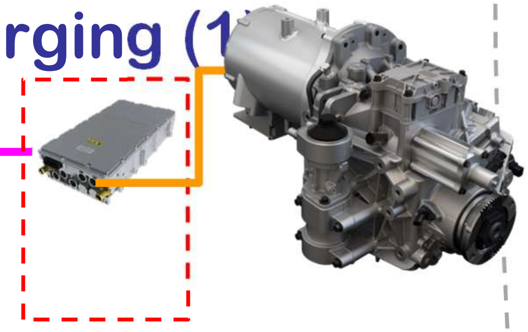
Solutions for galvanic isolation with AC Charging (1

AUX

BATTERY



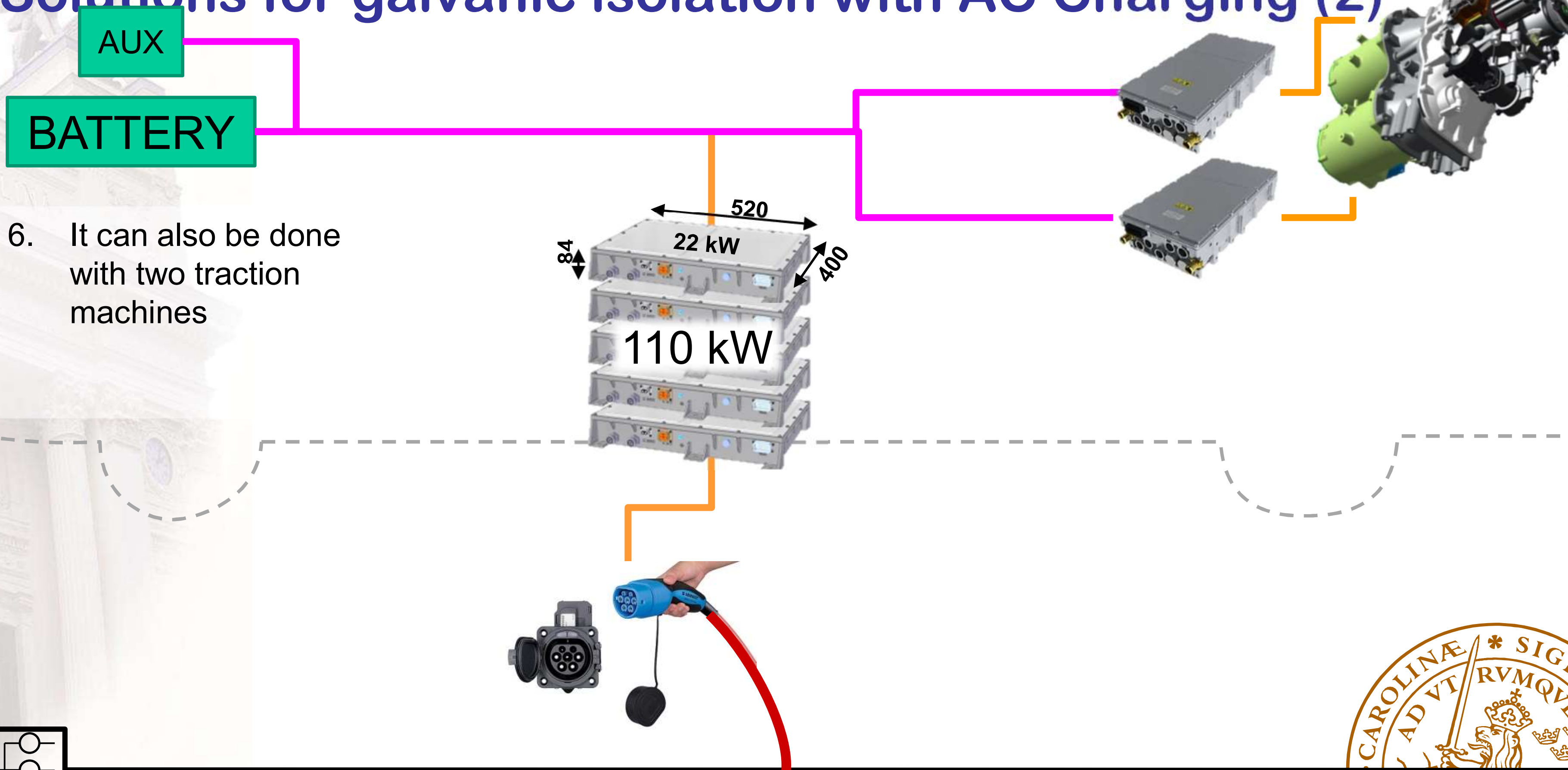
1. ON board chargers are always galvanically isolated.
2. We can use some of them, like in this example 5x22 kW = 110 kW
3. Weight: 100 kg
4. Size: 520x400x420



PEC

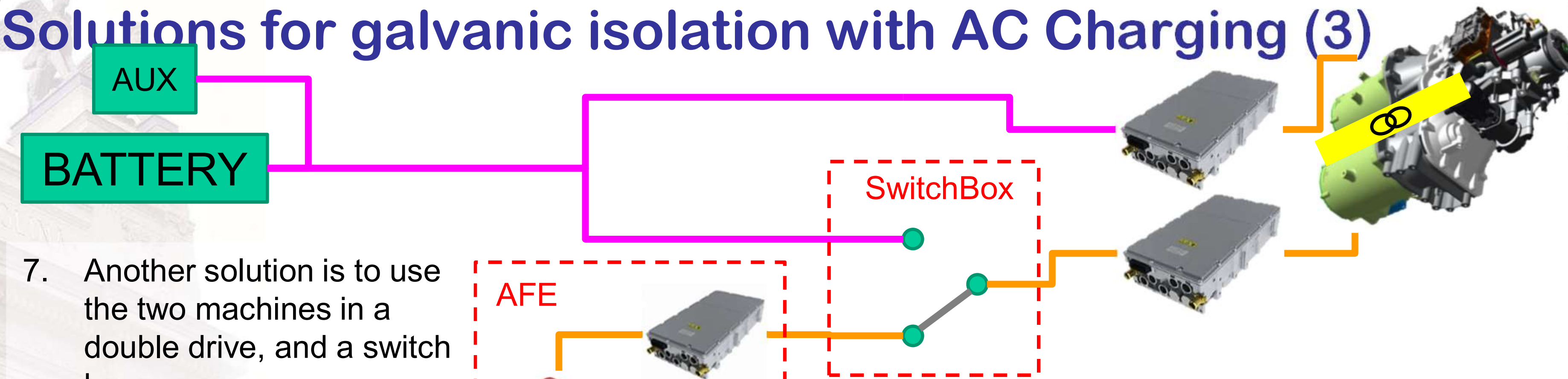
5. That is with one traction machine

Solutions for galvanic isolation with AC Charging (2)



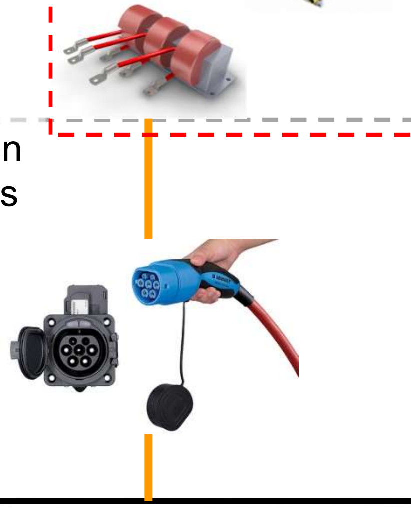
6. It can also be done with two traction machines

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.

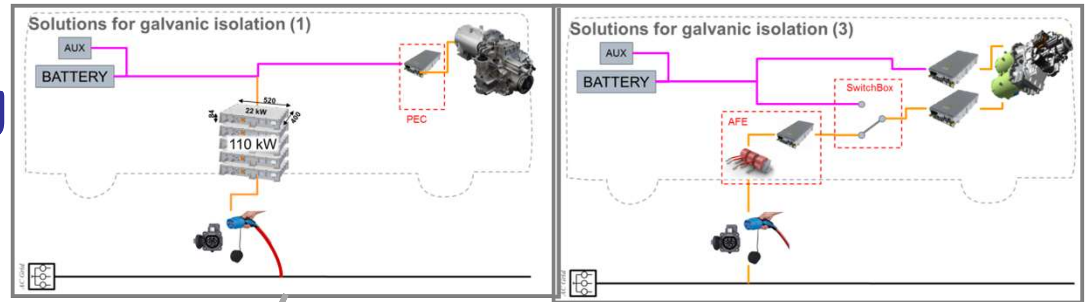
11. The *system cost* including EM+EMD will be lower with integration, about -20 %

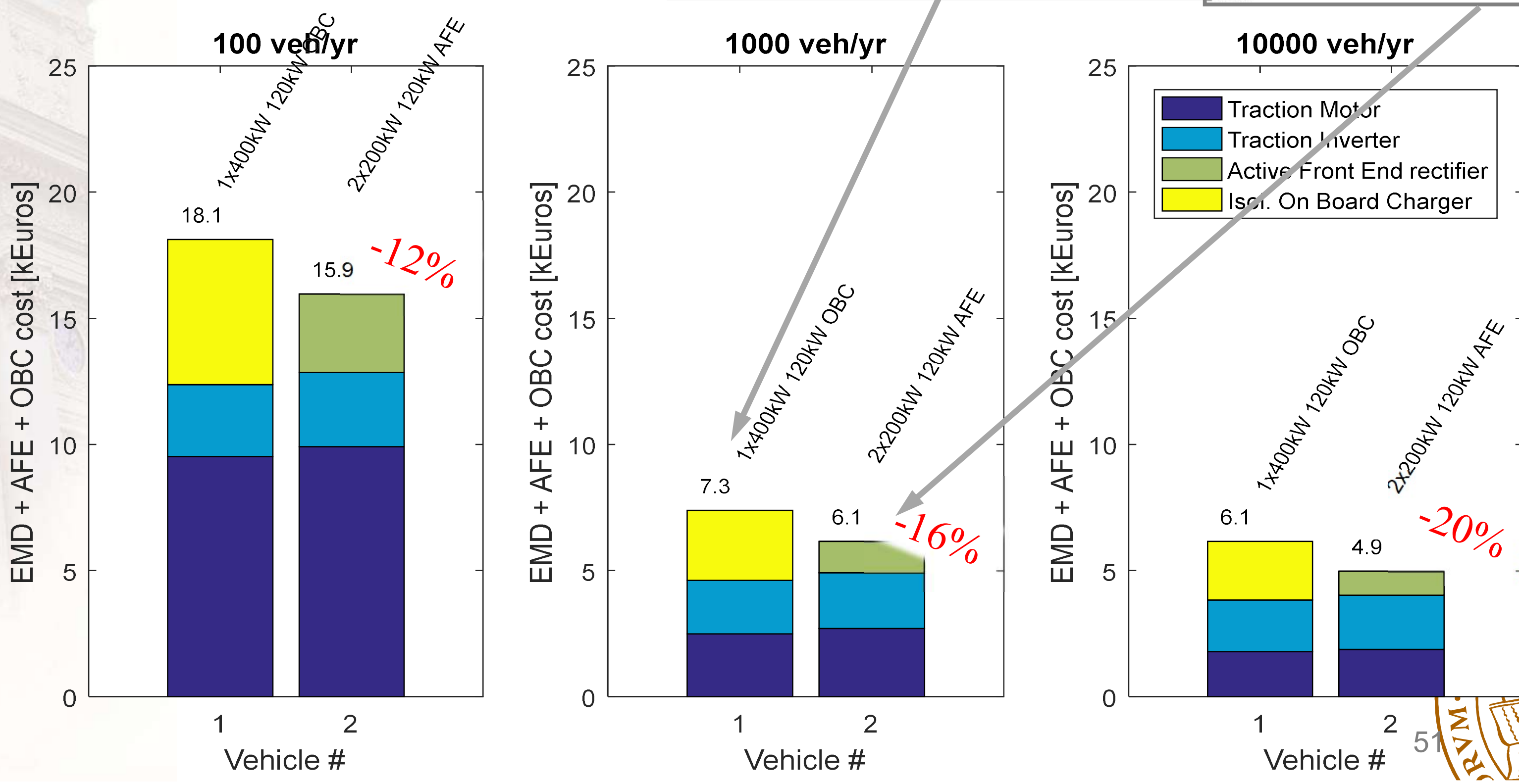
System Cost AC Charging

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

OR

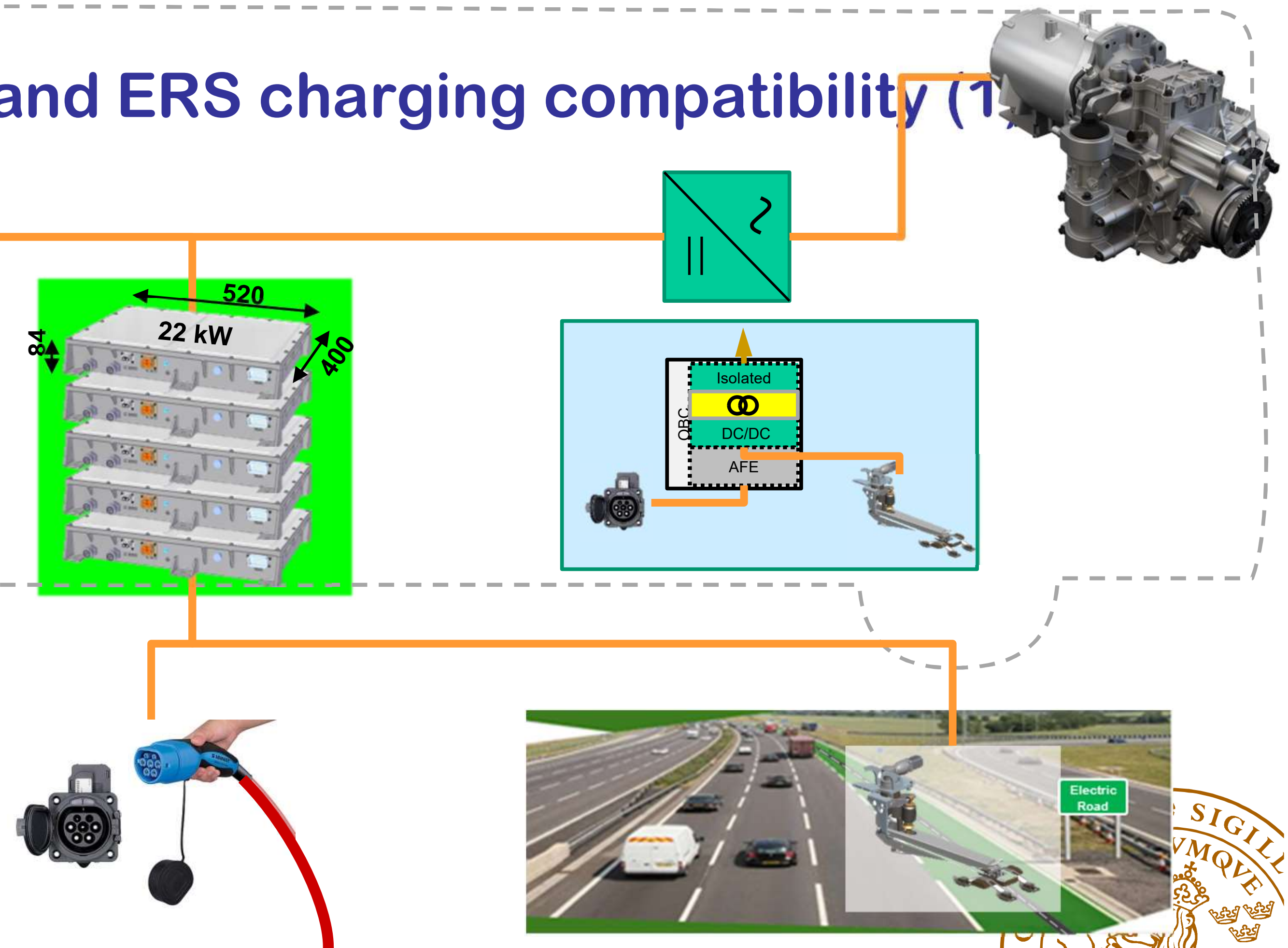
2 x 120/200 kW Cont/Peak





Including ERS Charging

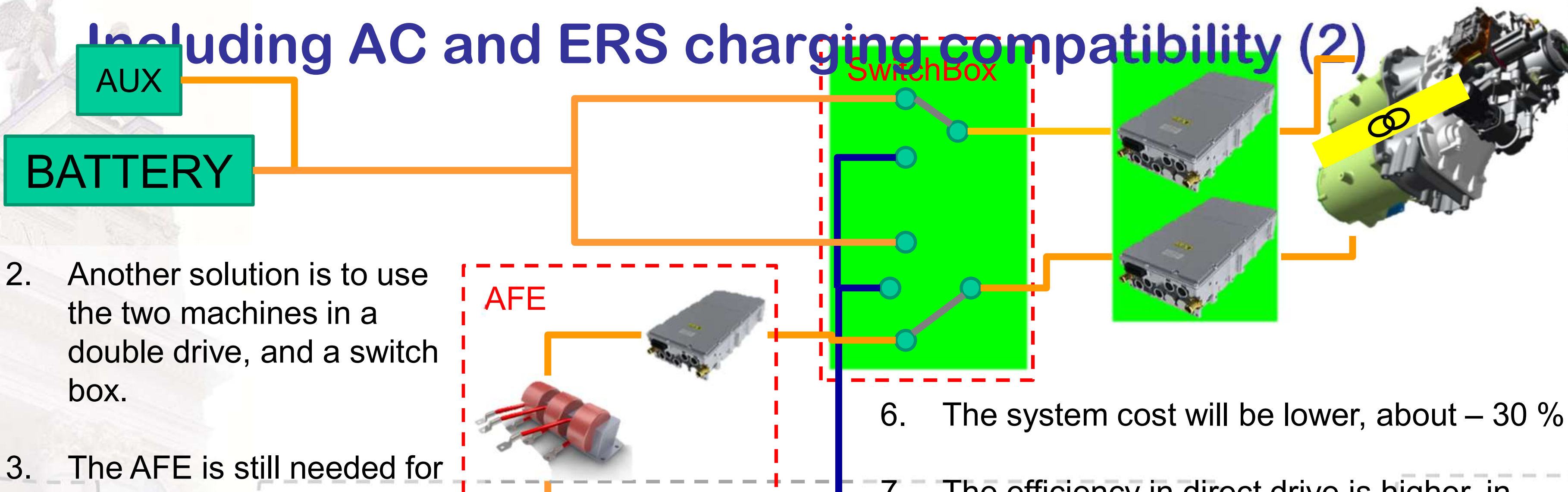
Including AC and ERS charging compatibility (1)



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

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

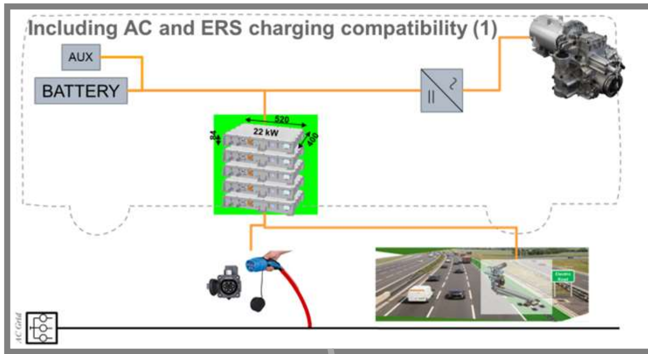
5. The MDS, the Switch Box and the Traction Machines need to be Double Isolated

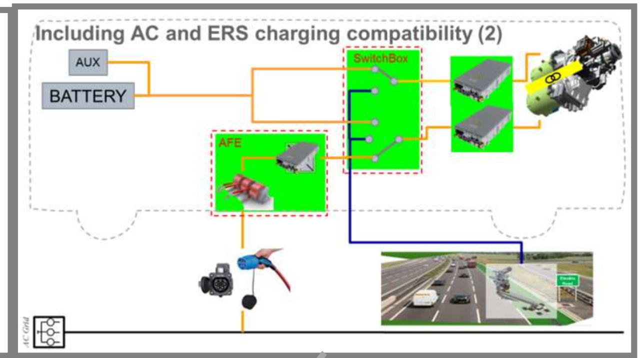
6. The system cost will be lower, about – 30 %

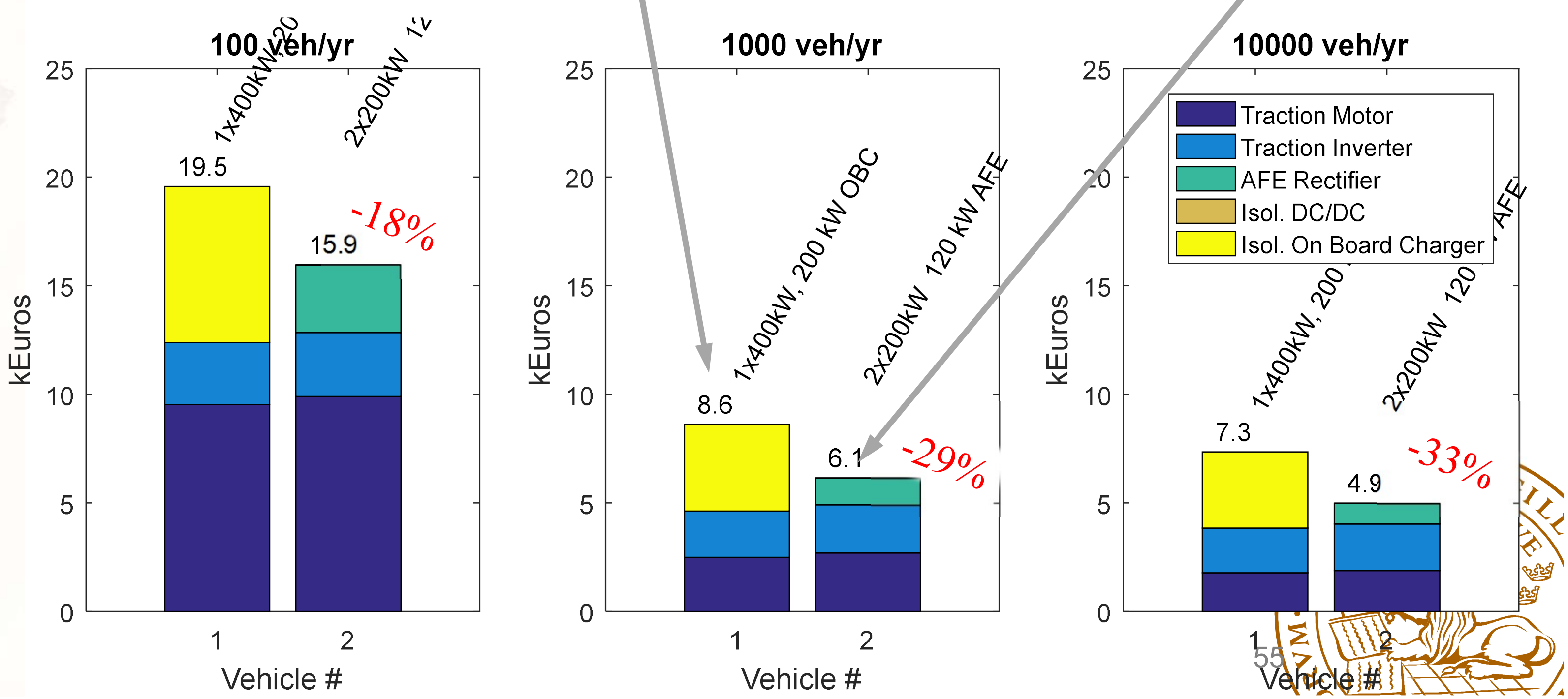
7. The efficiency in direct drive is higher, in charging is lower compared to previous alternative.

AC+ERS System Cost

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



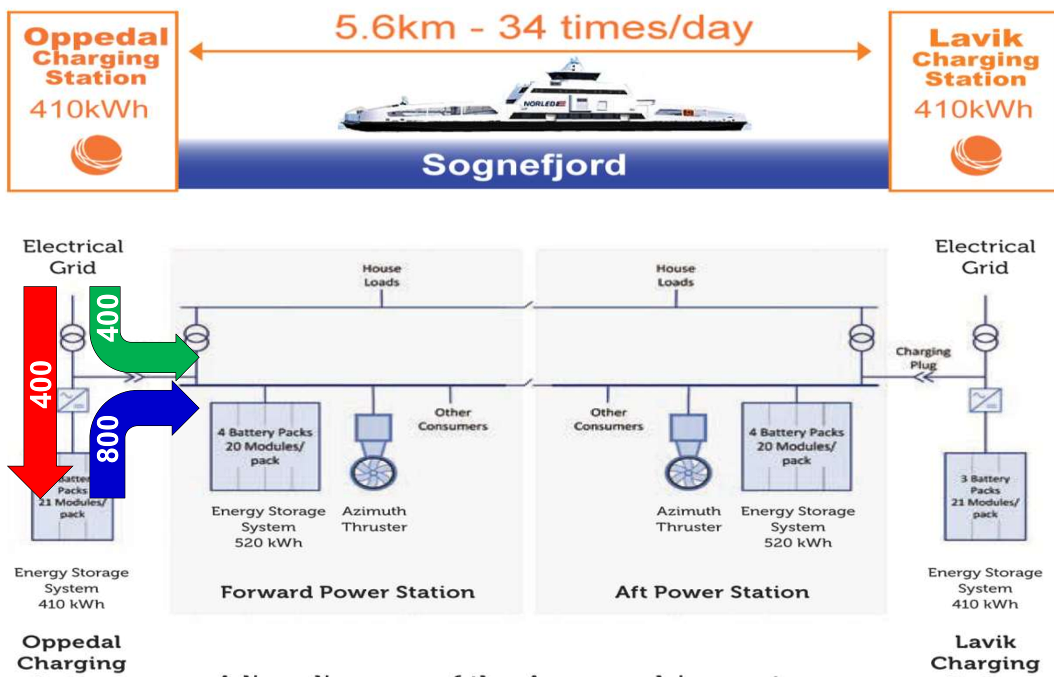





Can all this be used off road?
NORLED

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 ?

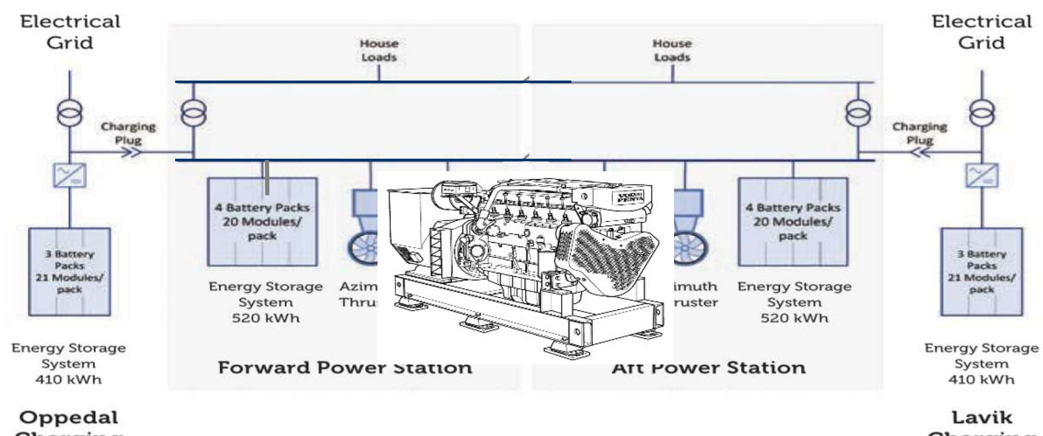
- **Bigger battery + more charging?**

- **”Pain limit” reached?**

- **Fill in with HYBRID !**

- **Here, a Series Hybrid!**

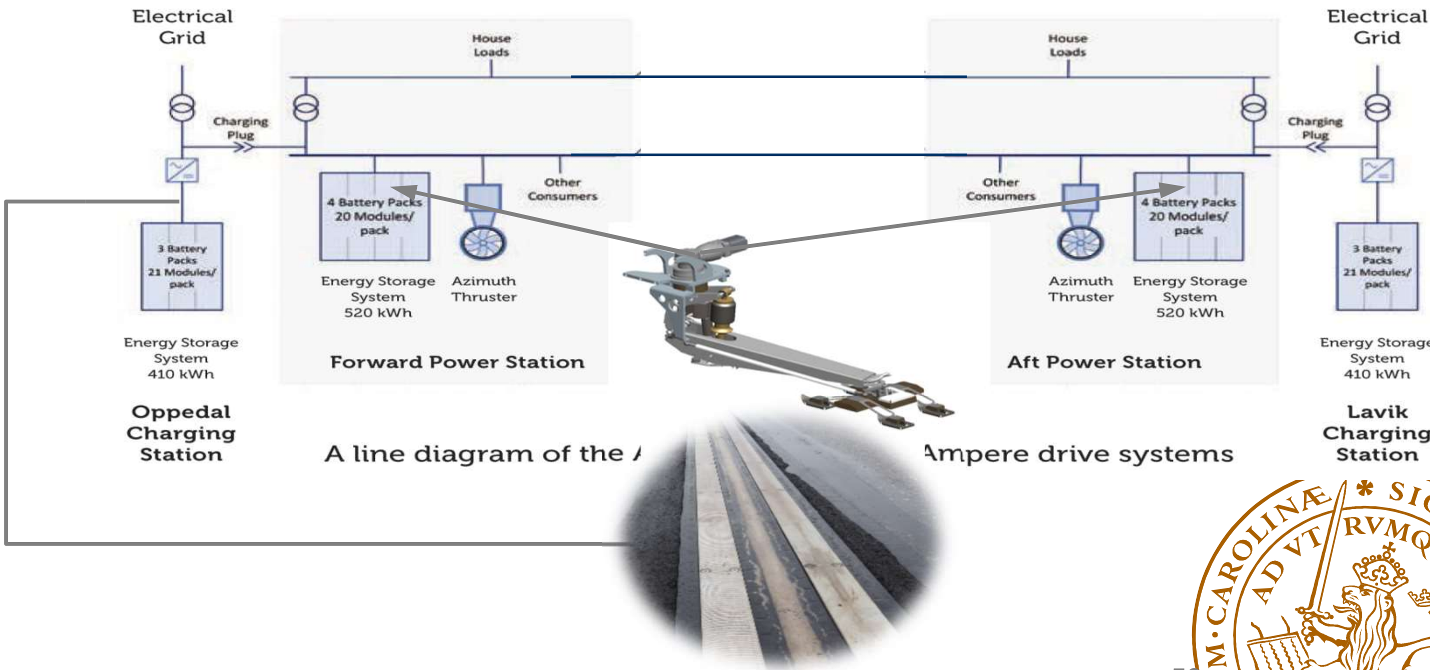
- **Can also be a Parallel Hybrid!**
  - Combustion engine drive directly on the Thruster
  - Use a Hybrid Drive for e.g. Buses?



A line diagram of the Ampere drive systems

And what if it was on land?

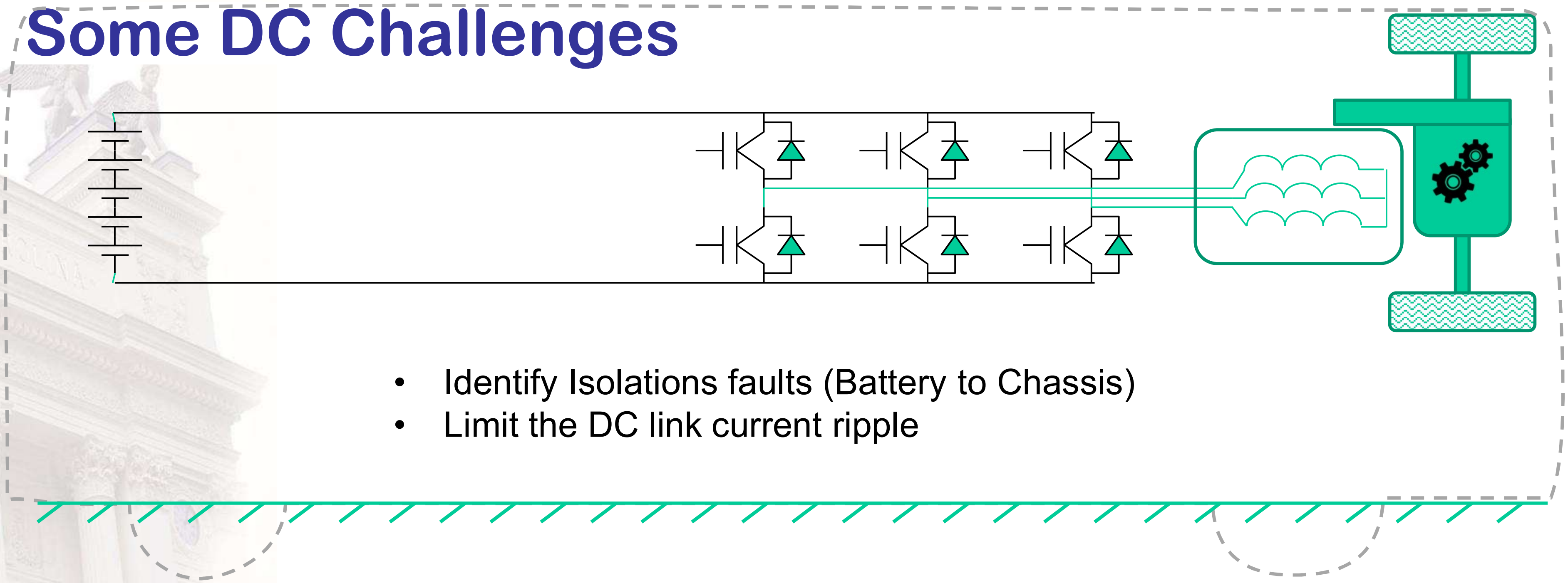
- **No Hybrid Needed!**
- **Use Dynamic Charging to ”fill in”**



Current Loading

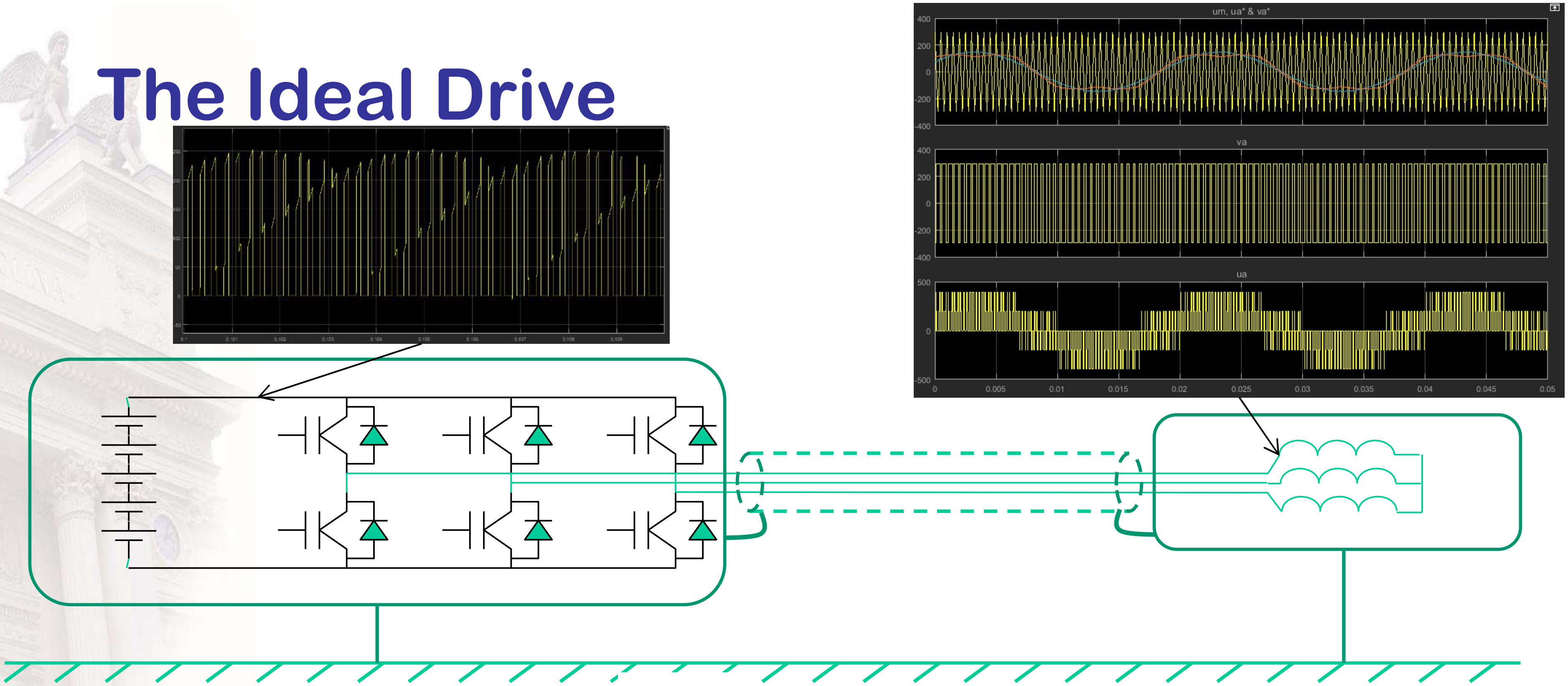
Charging Solutions

Some DC Challenges

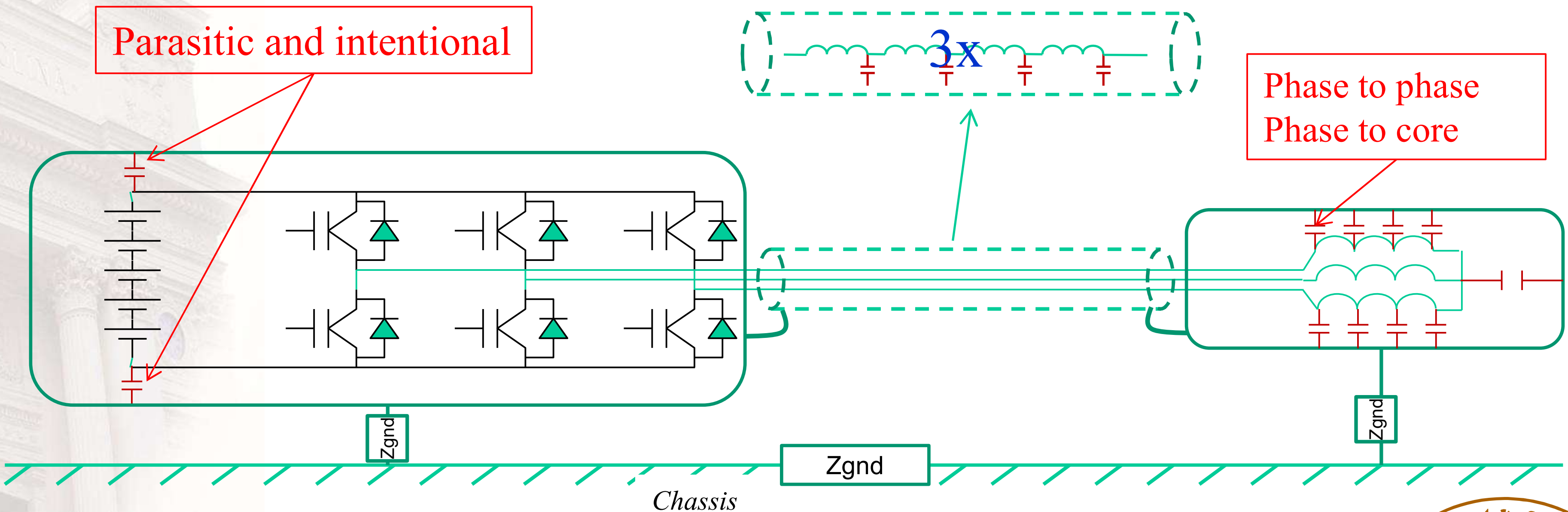


- Identify Isolations faults (Battery to Chassis)
- Limit the DC link current ripple

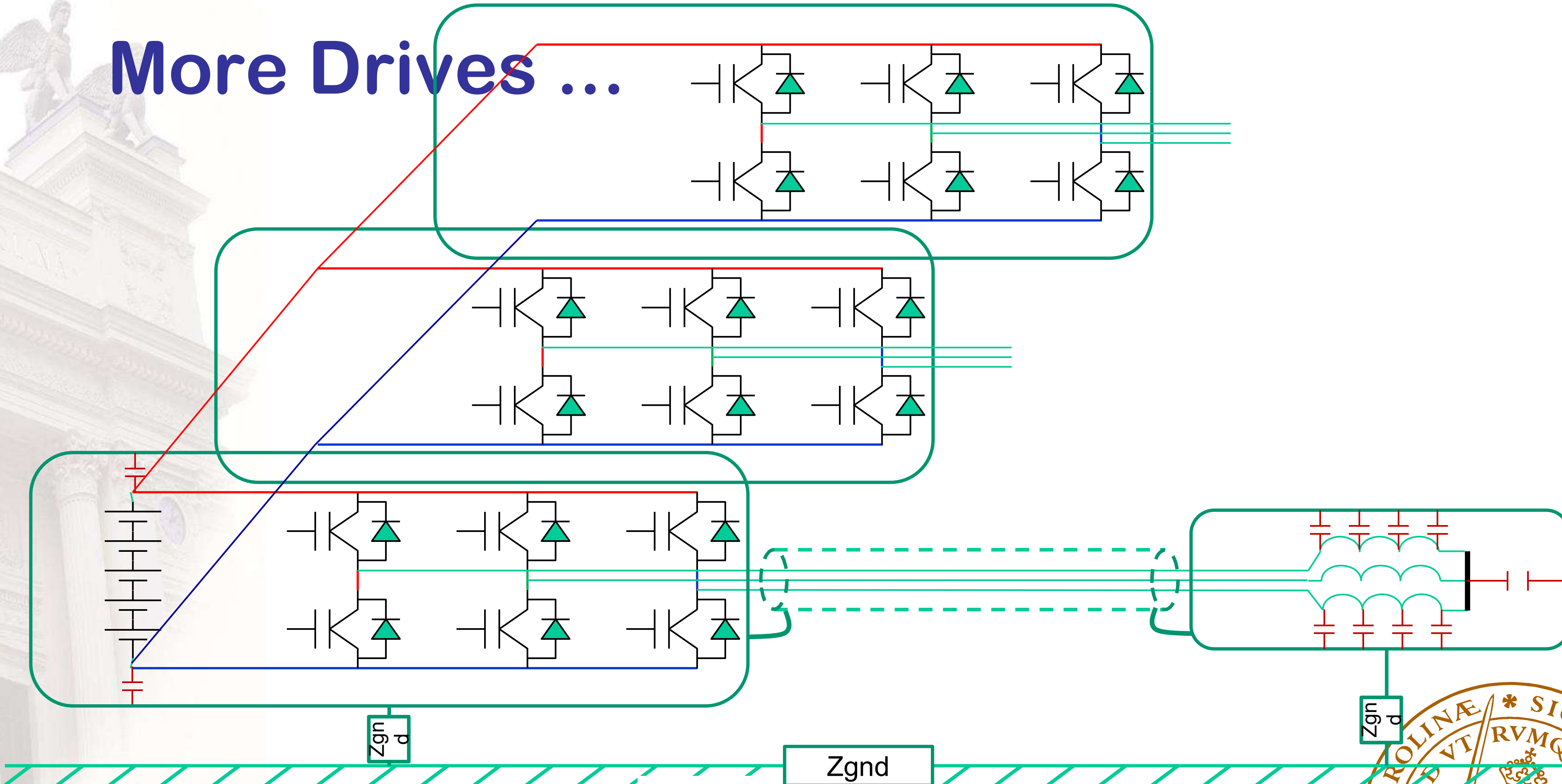
The Ideal Drive



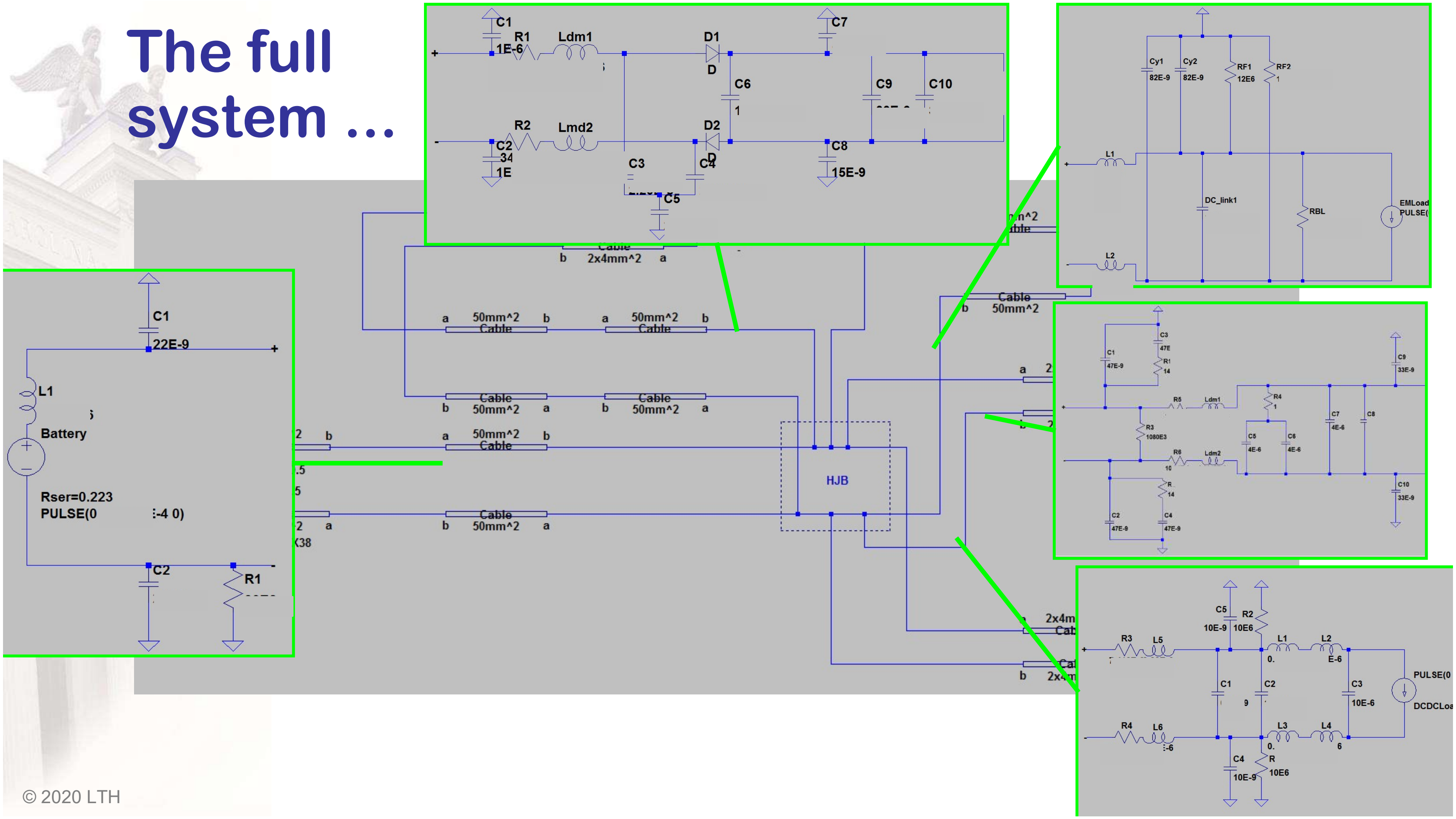
Some parasitics ++

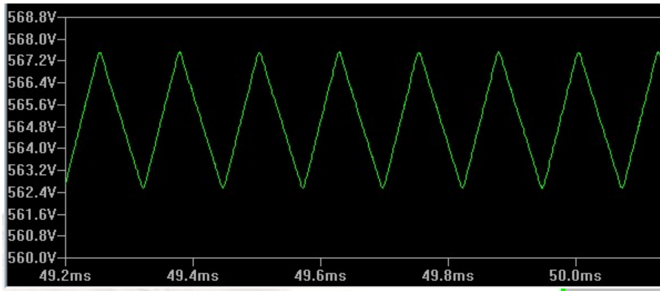


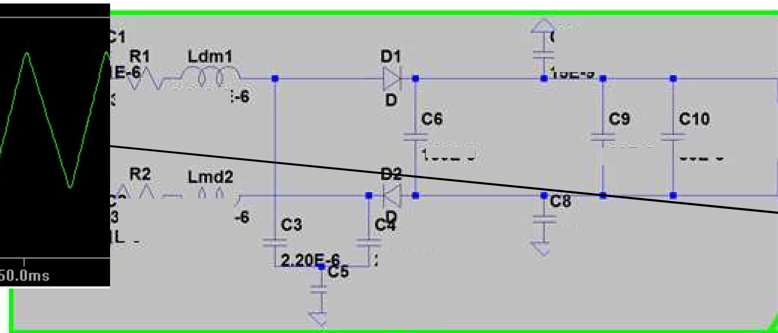
More Drives …

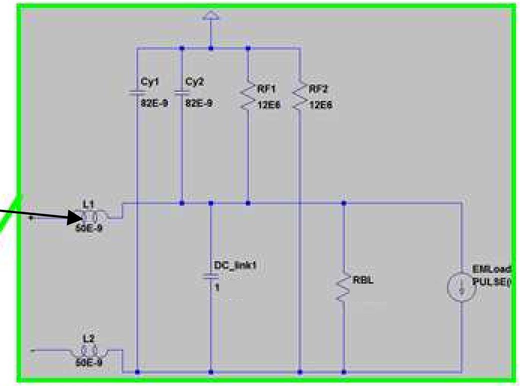


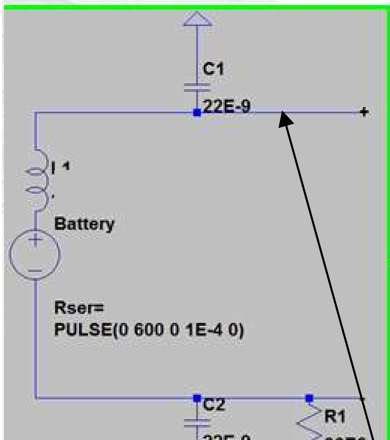
The full system ...









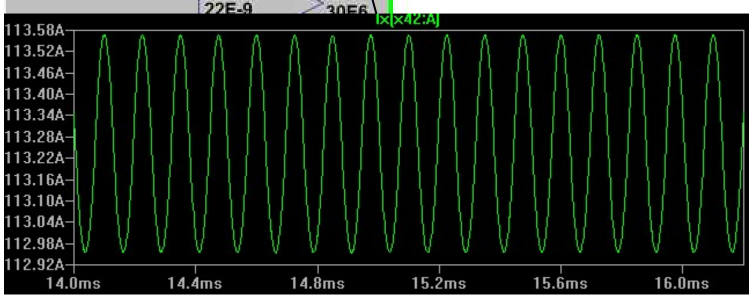


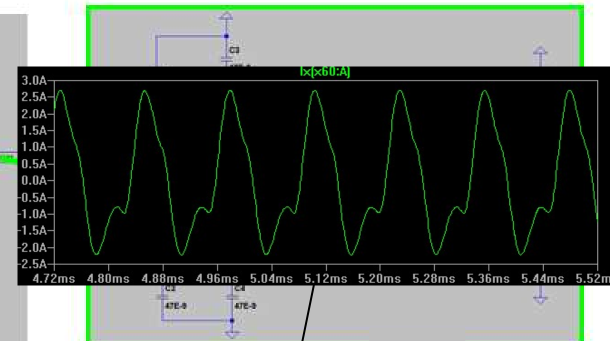
Some conclusions:

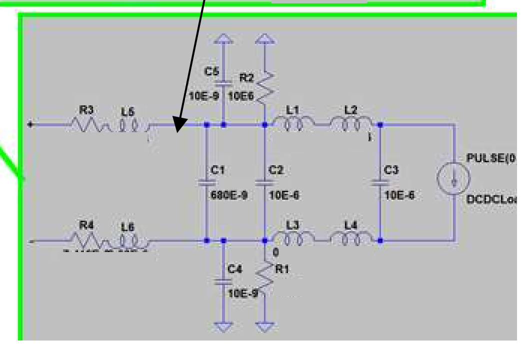
1 A Complex circuit

2 A High Excitation

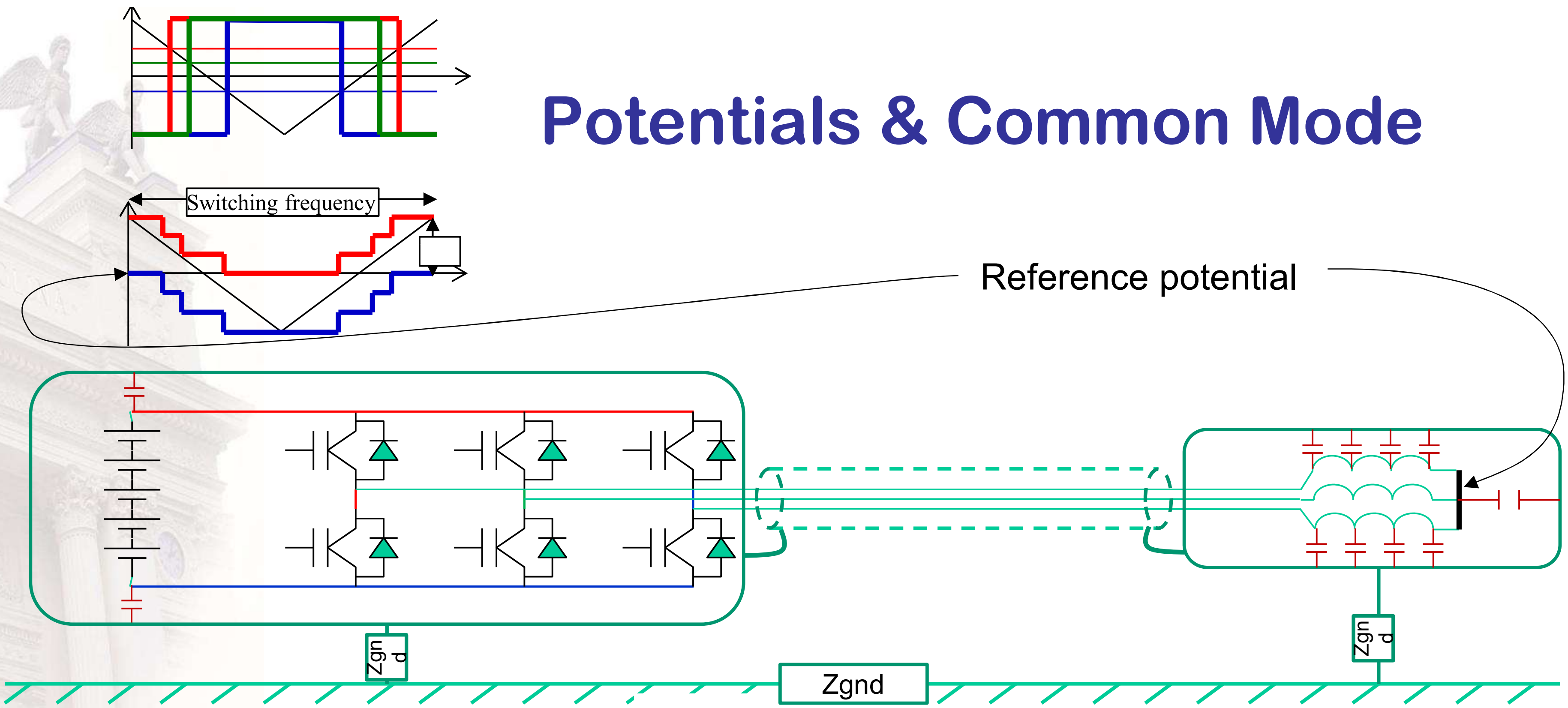
3 Complex harmonics distribution



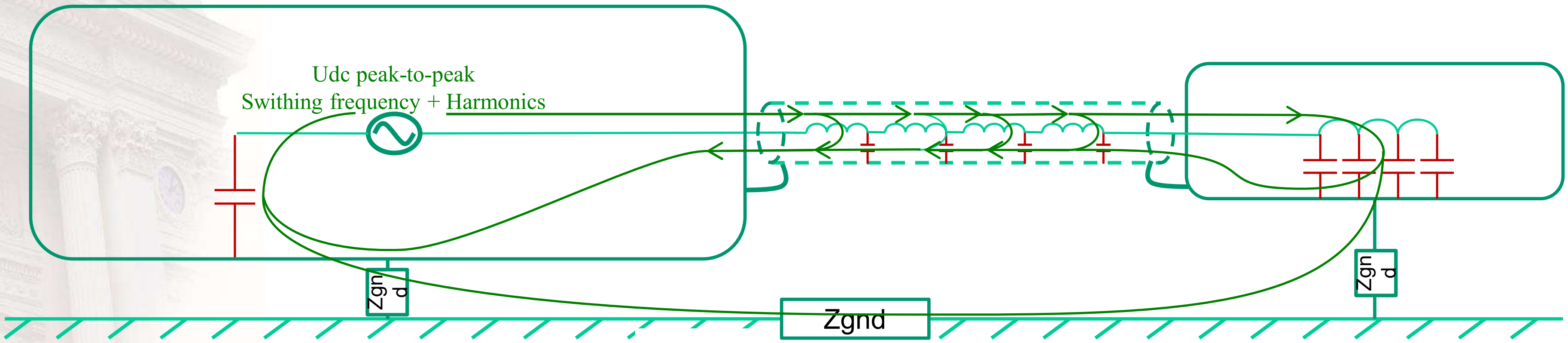




Potentials & Common Mode

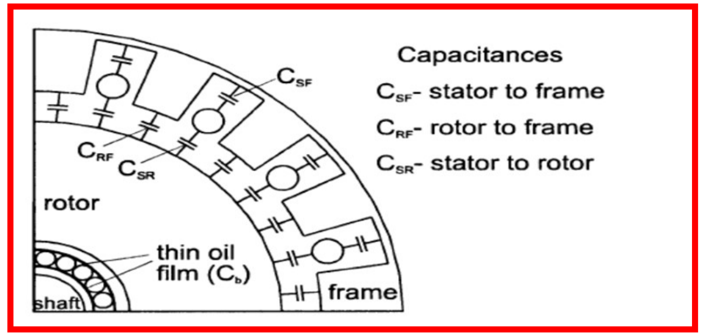


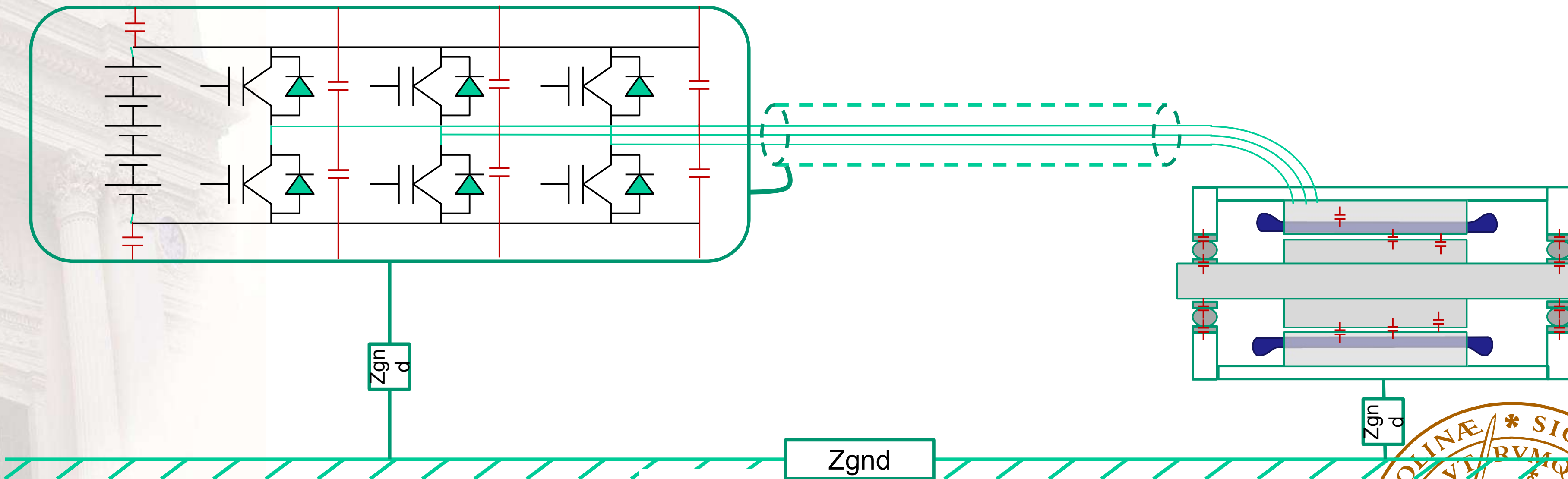
Equivalent Circuit



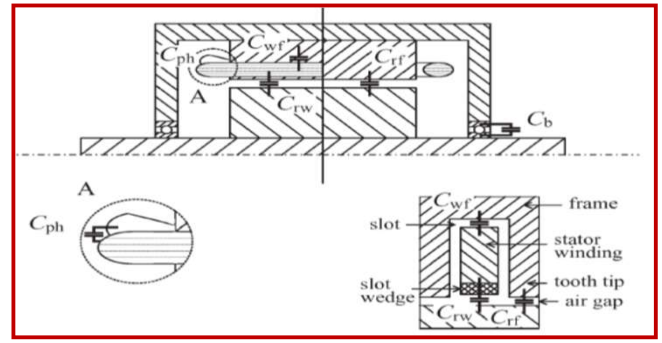
Some more parasitics

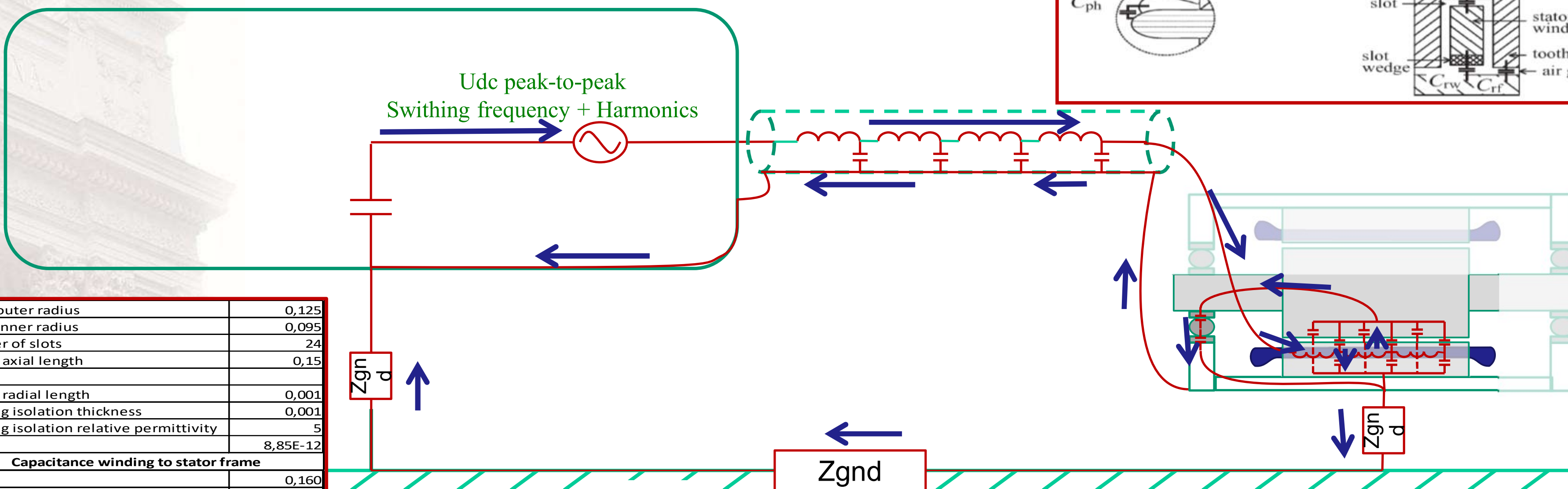
+++





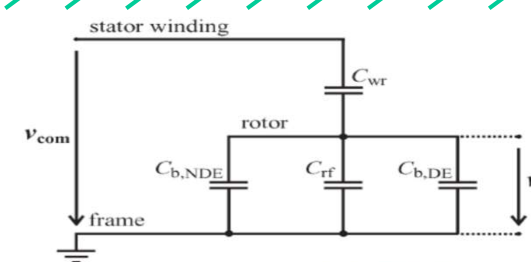
Equivalent Circuit ++





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


ELSEVIER

Journal of Electrostatics 51–52 (2001) 416–423

Journal of ELECTROSTATICS

www.elsevier.com/locate/elstat

Capacitively coupled discharging currents in bearings of induction motor fed from PWM (pulsewidth modulation) inverters

Adam Kempski*

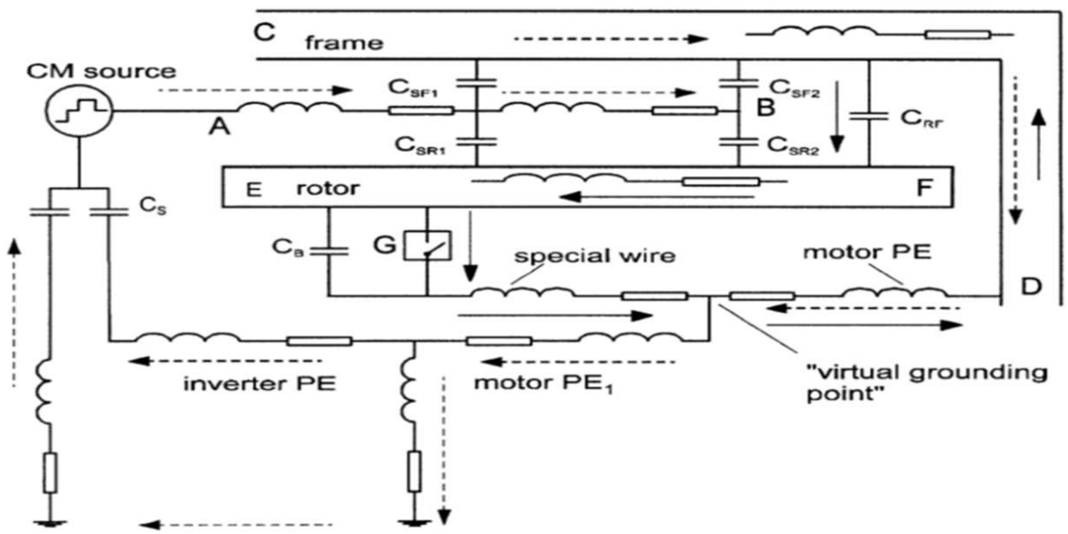
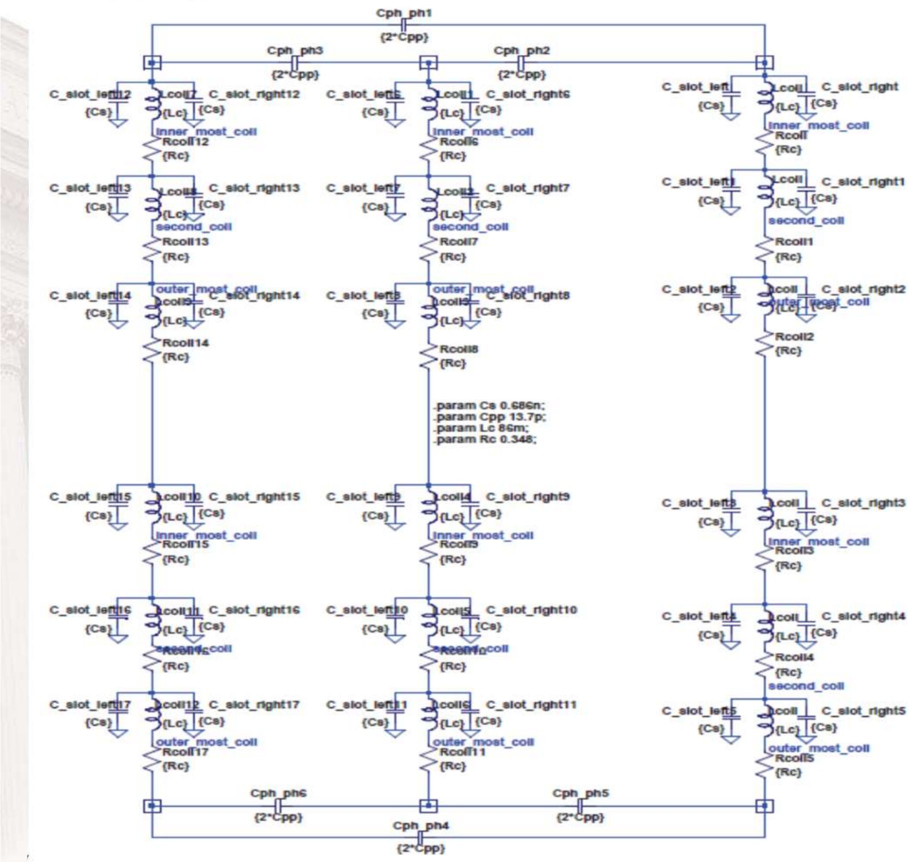
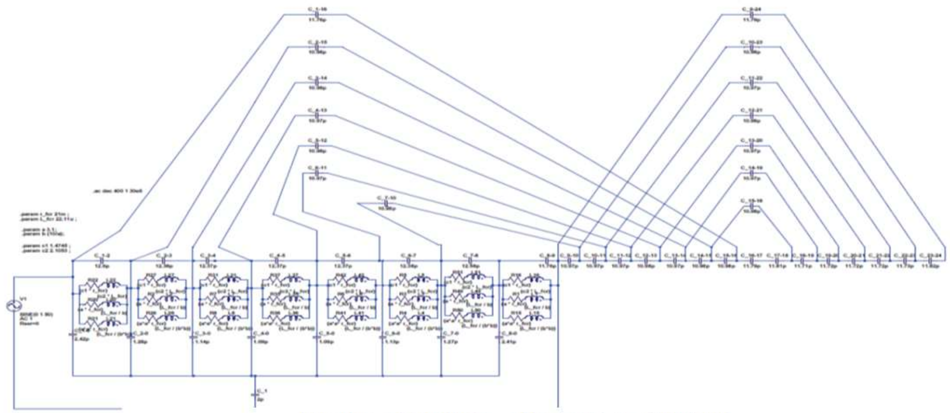
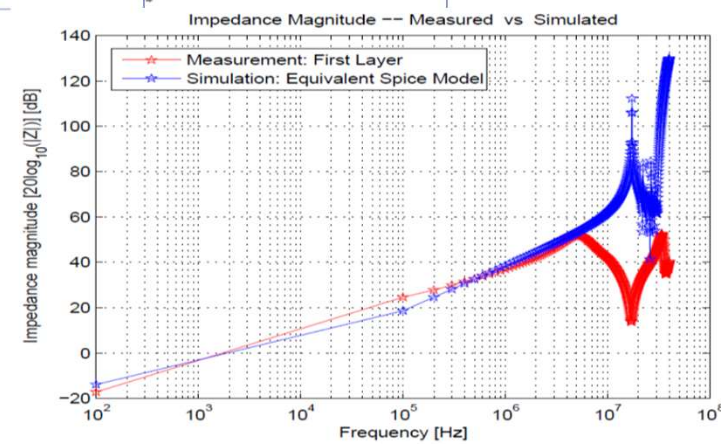


Fig. 8. Common mode equivalent model.

More details ...

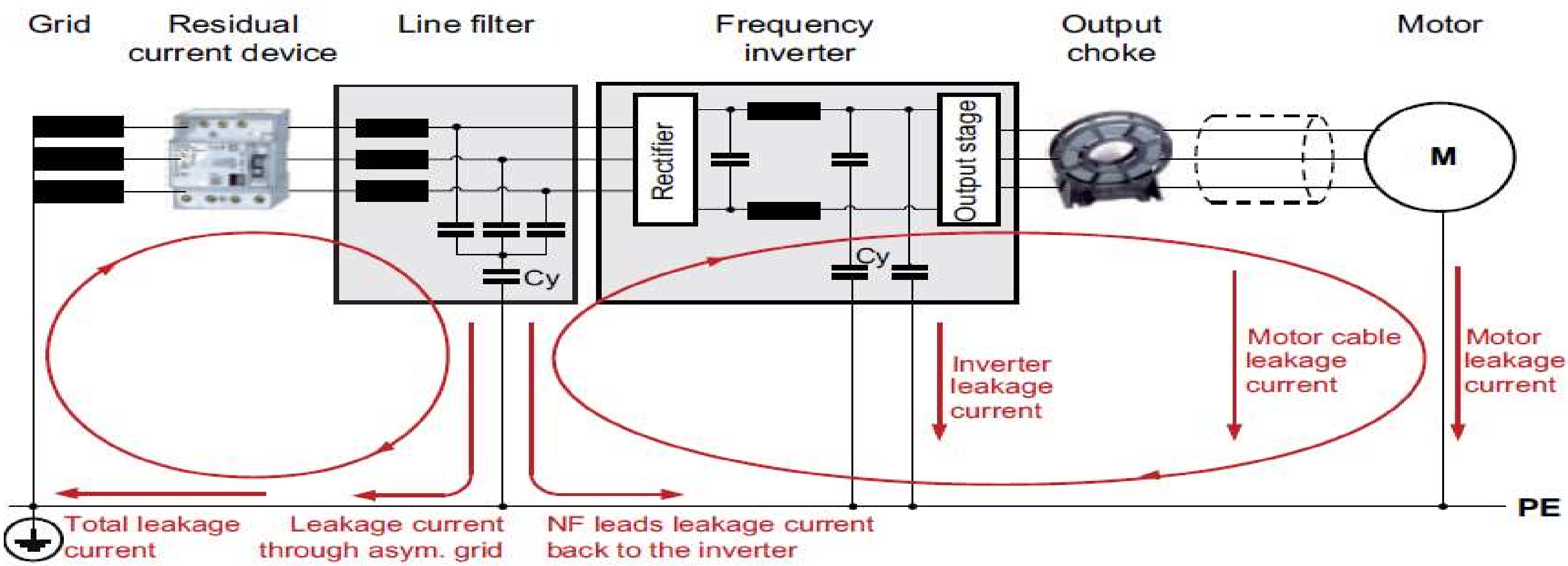




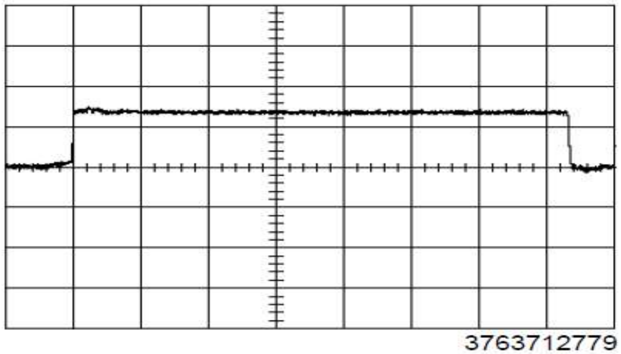


Leakage current damping

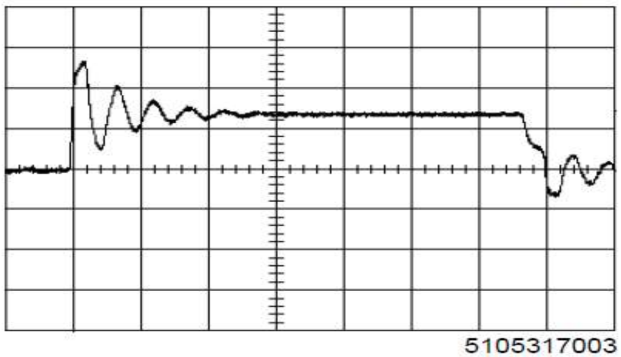
The following figure shows the leakage currents of a controlled drive with suitable EMC measures.



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



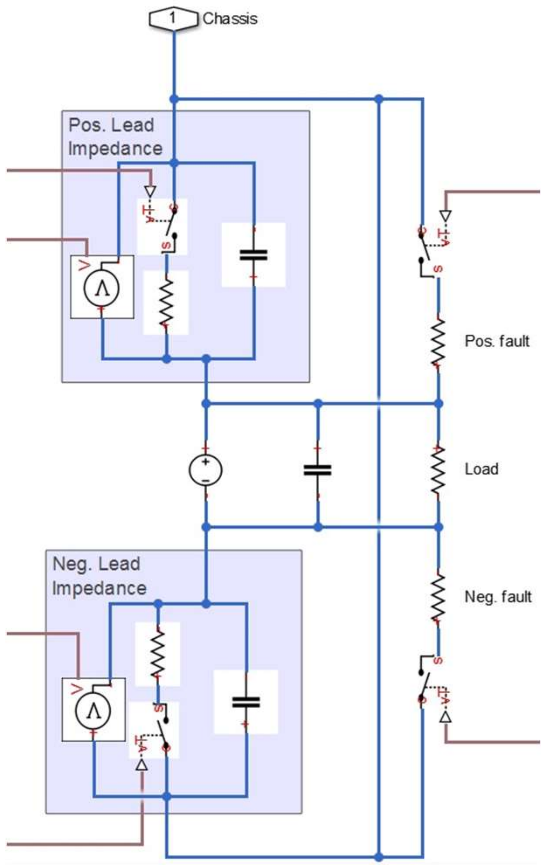
Voltage characteristics
at the output of the frequency inverter



Voltage characteristics
at the motor terminals

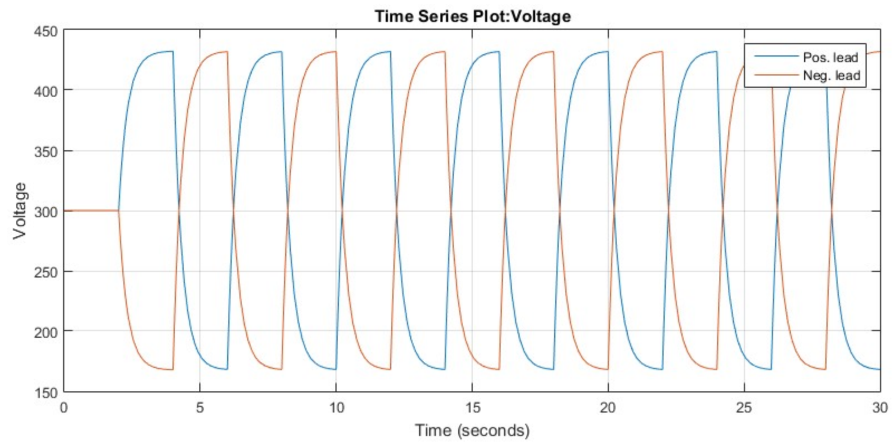
Floating GND

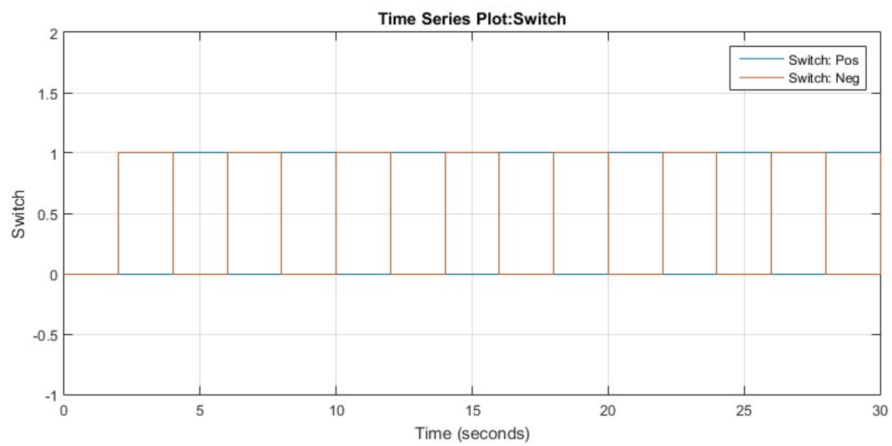
- R @chassis = 375kOhm
- C @chassis = 700nF
- C @line-to-line = 1500microF
- V @battery = 600 V
- Controlled Faults



Without Faults

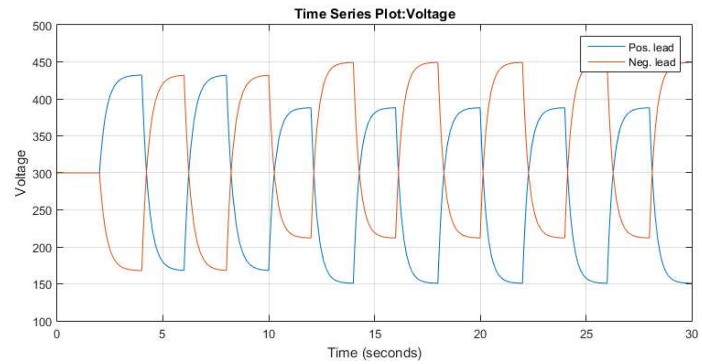
- Switching Time = 2 s
- No Faults
- Voltages ~300±130 V



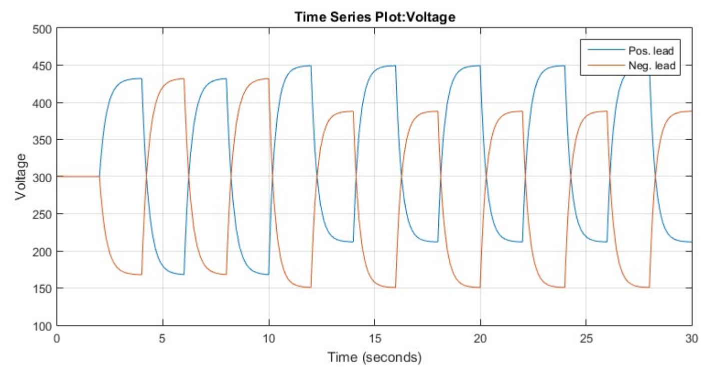


1 Mohm isolation faults

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

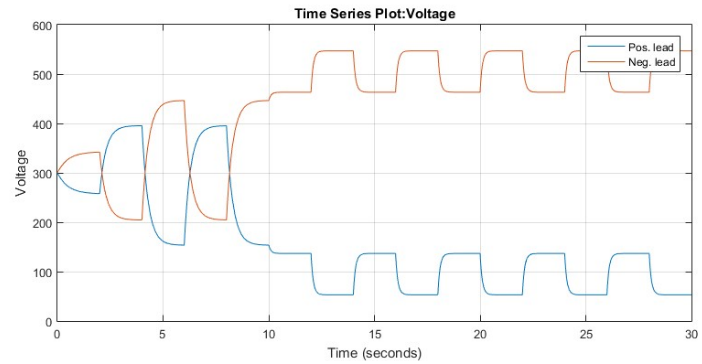


- Bottom
  - Fault @neg. = 1MOhm

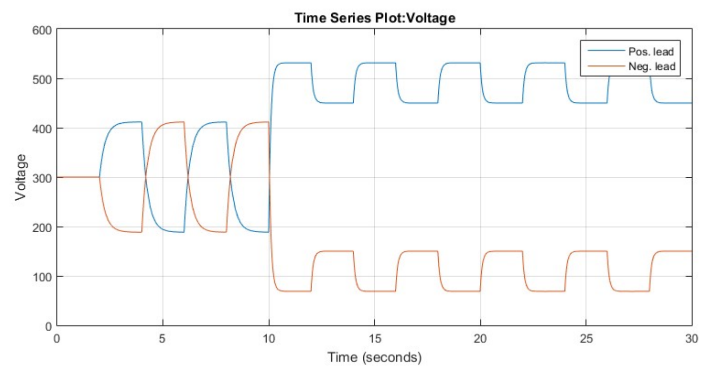


100 kOhm faults

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

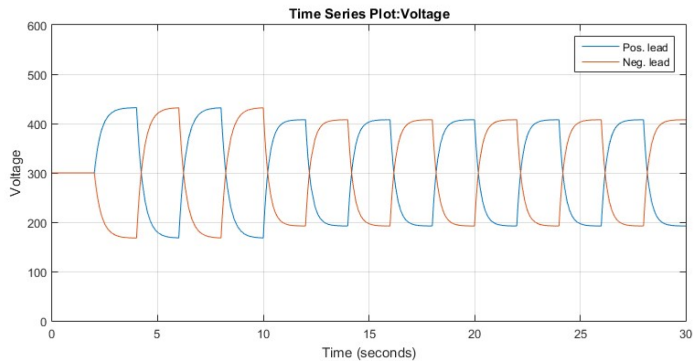


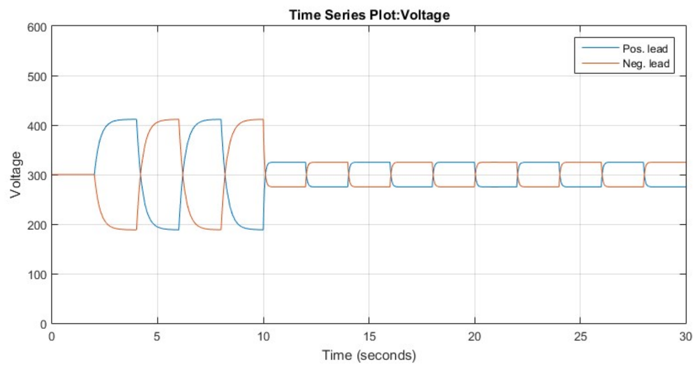
- Bottom
  - Fault @neg. = 100kOhm



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.