A 20 kW high efficiency on-board bidirectional battery charger

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PE: Region seminar

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Mads Clausen Institute

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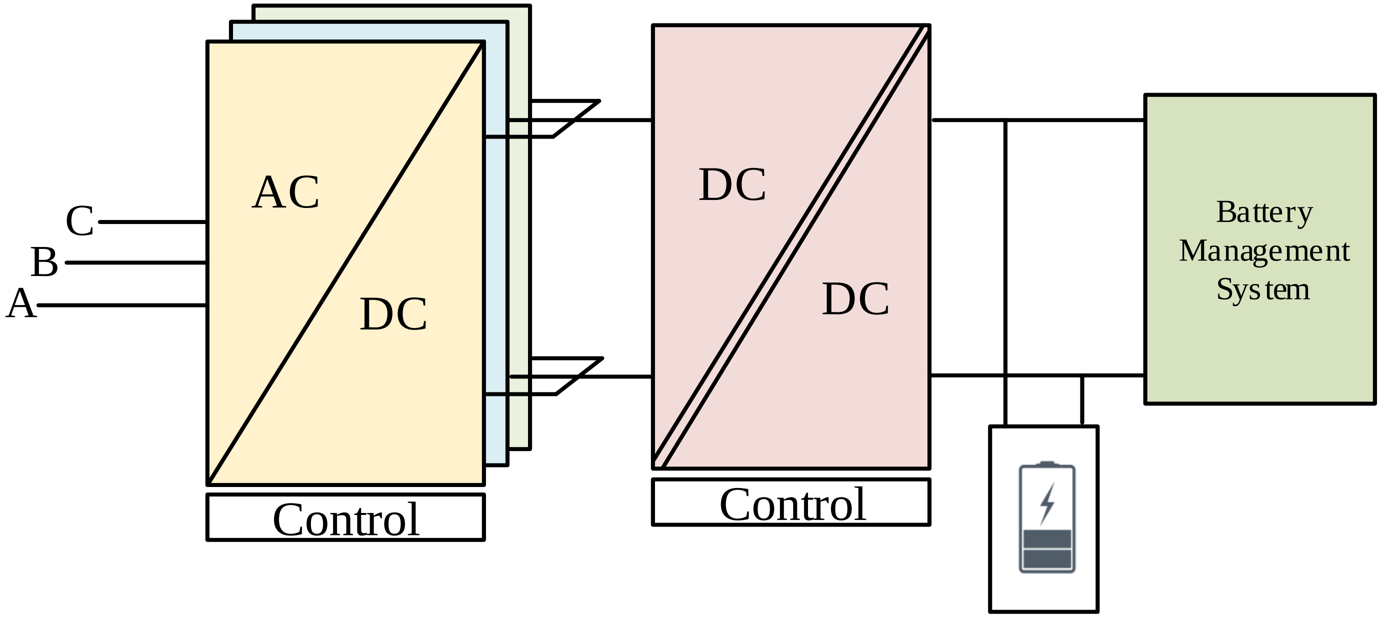
Outline

- Objective
- High power battery charger
- PFC (ac-dc converter)
- Isolated dc-dc converter
- Magnetic design
- Hardware prototype
- Prospects

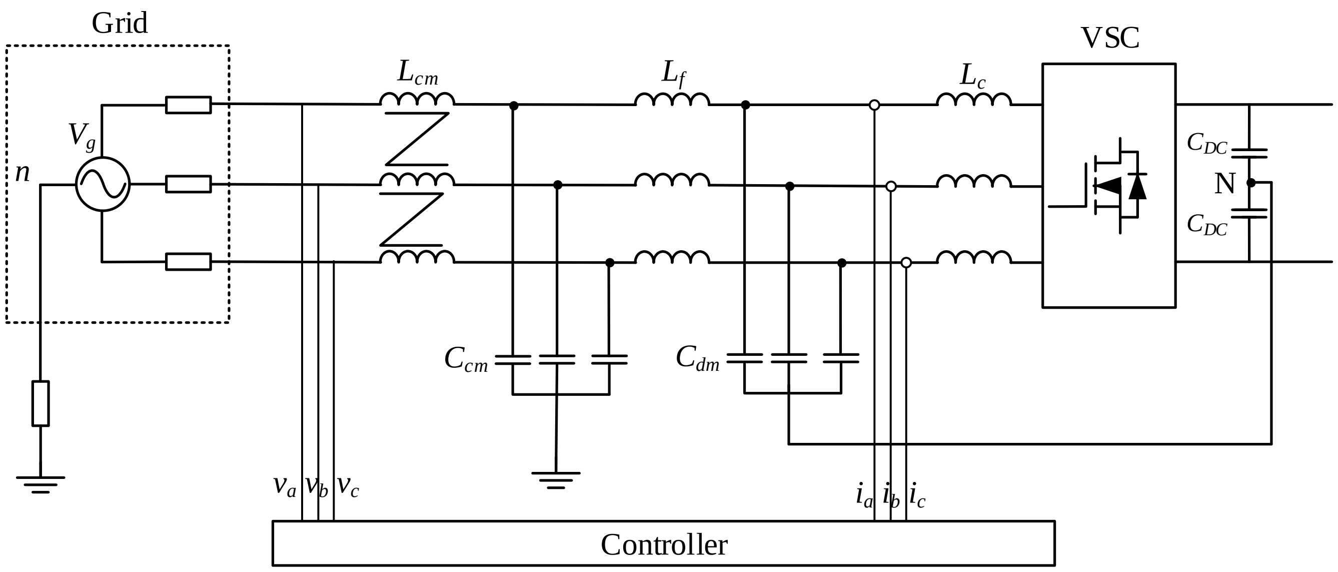
Objective

- To demonstrate the highest achievable conversion efficiency in a high power battery charger - the ac-dc rectifier and the dc-dc power converter modules



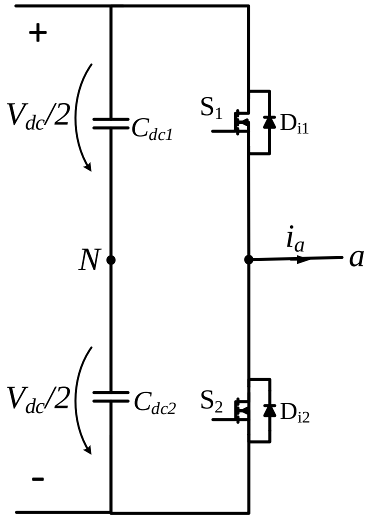
PFC(AC-DC)

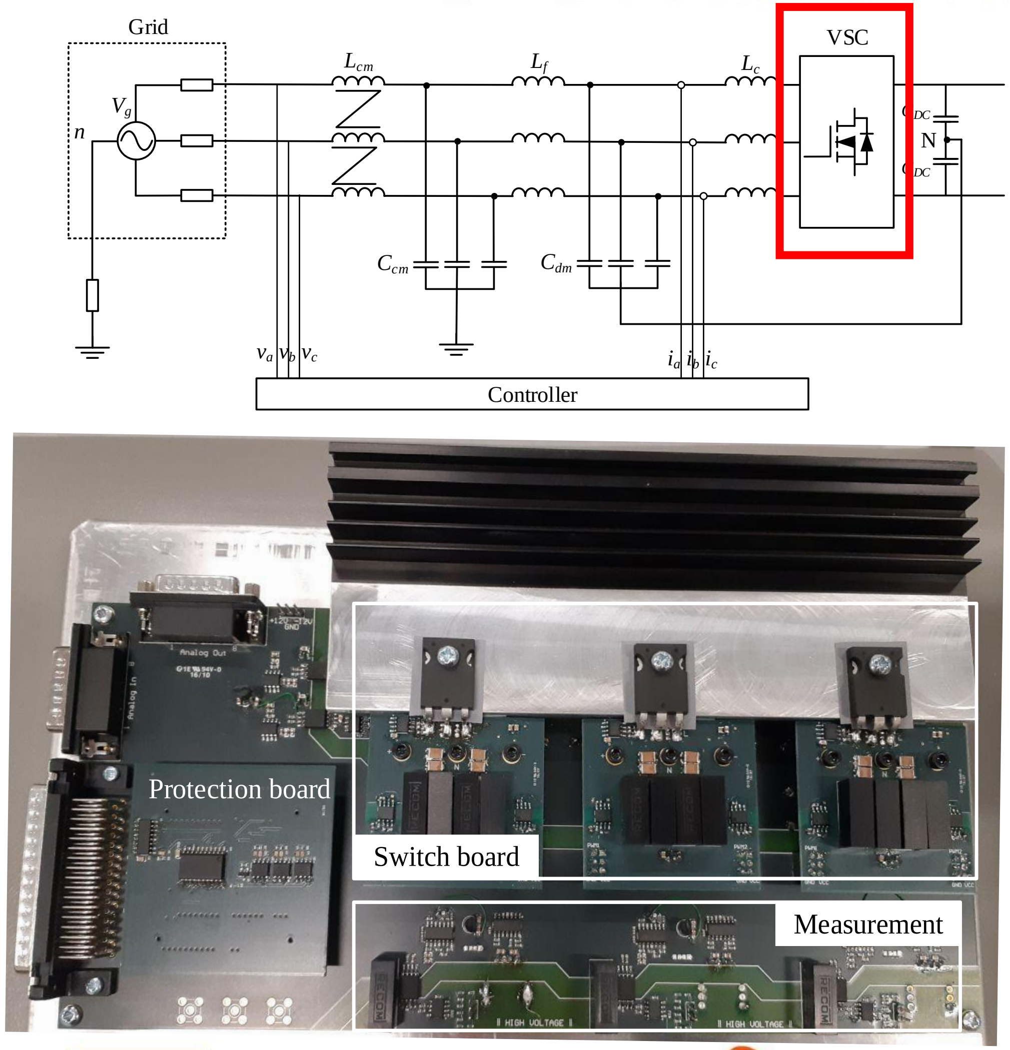
Variable	Description	Value
P_{nom}	Nominal power	20kW
V_{ac}	Phase source voltage	230 V
V_{dc}	DC link voltage	700 V
f_g	Grid frequency	50 Hz
f_s	Switching frequency	100 kHz



PFC(AC-DC)

2 x SiC MOSFET, 1200 V, 95 A, 22 mΩ (SCT3022KL)

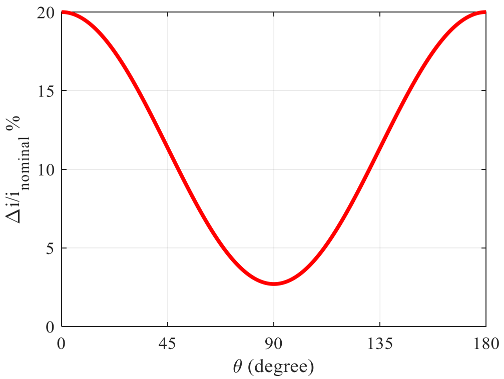


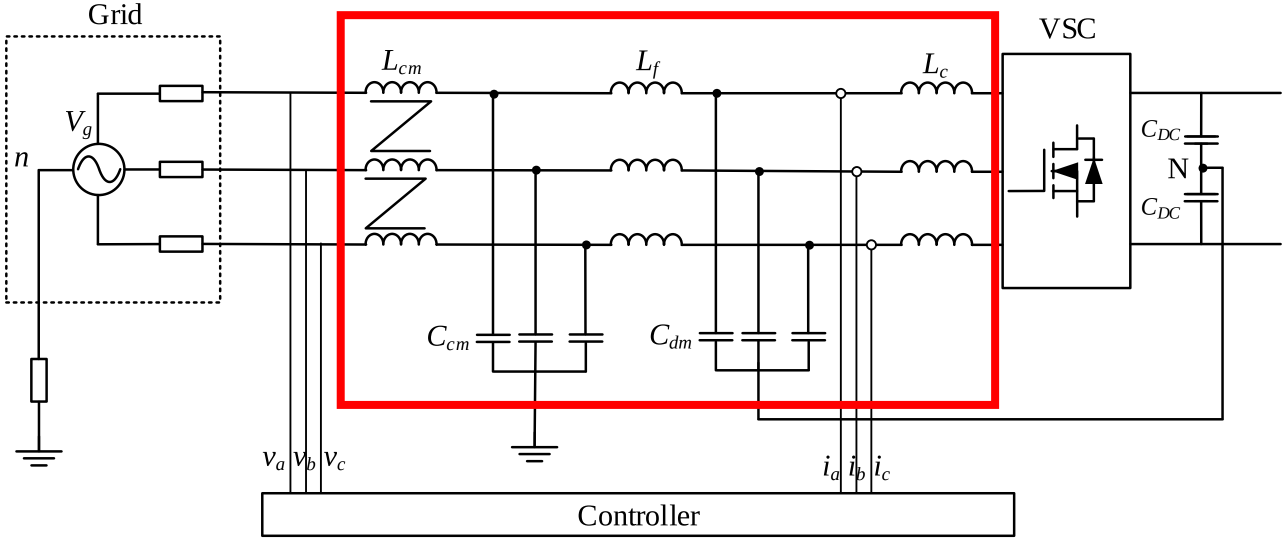


PFC(AC-DC)

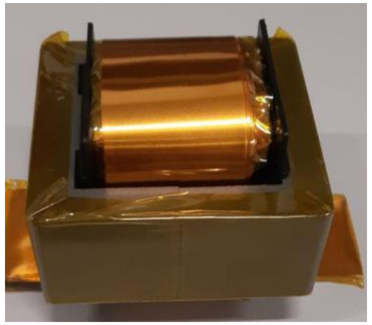
Boost inductor

maximum acceptable current ripple →20%

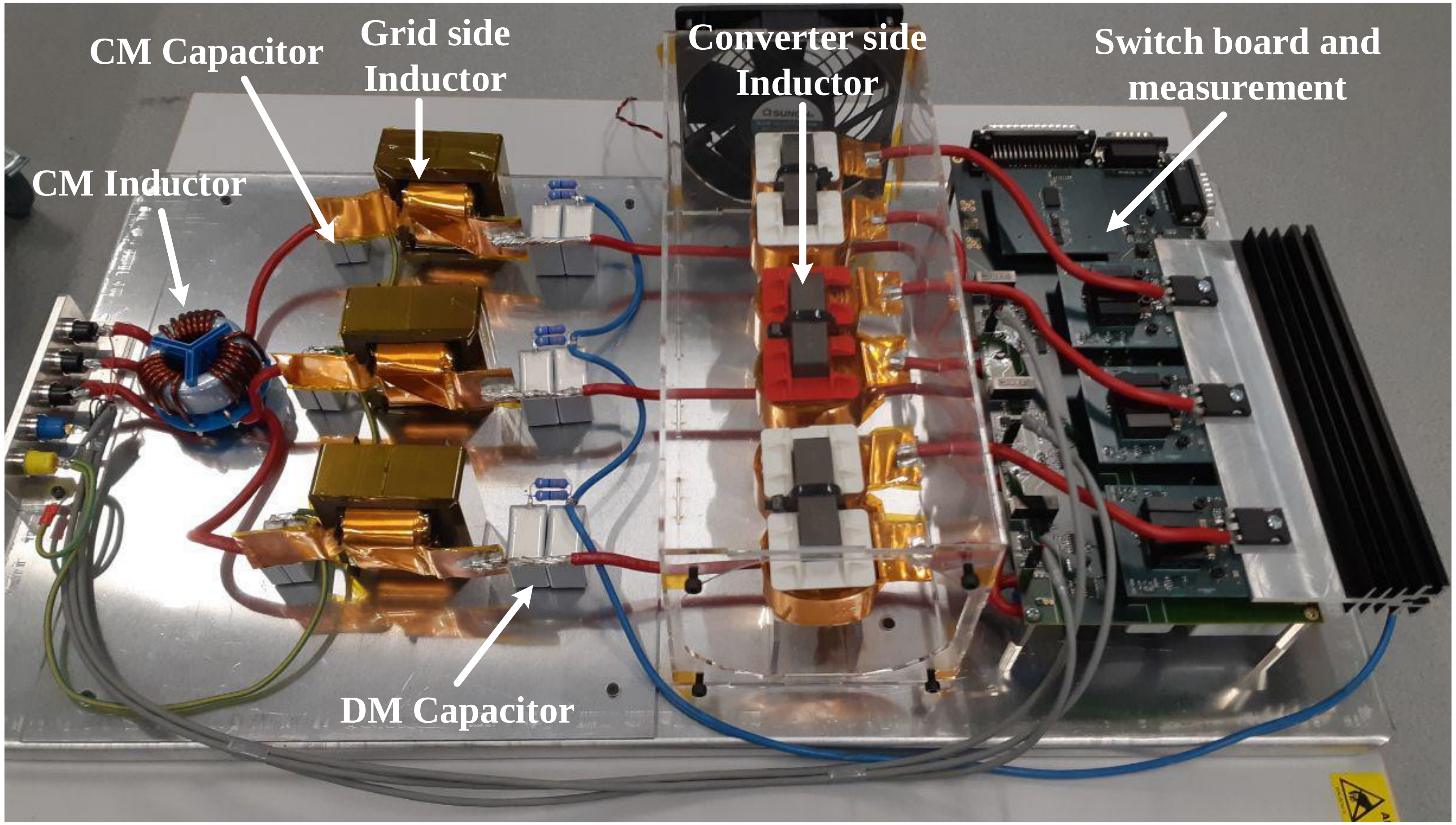




Variable	Description	Value
L_c	Converter side inductor	220μH
L_f	Grid side inductor	100μH
C_{dm}	DM capacitor	6μF
C_{cm}	CM capacitor	2μF
L_{cm}	CM inductor	700 μH



PFC(AC-DC)



CM Capacitor
Grid side Inductor
Converter side Inductor
Switch board and measurement
CM Inductor
DM Capacitor

PFC(AC-DC)

Differential Mode and Common Mode

DM	3rd	fs	2fs	3fs
Sinusoidal pulse width modulation (SPWM)	0.01	238	81	50
Space vector pulse width modulation (SVPWM)	61	225	97	90
Third harmonic injection pulse width modulation (THIPWM)	49	228	96	87
Space vector modulation (SVM)	61	225	97	90
Reduced common mode Space vector modulation (SVM_RCM1)	61	165	97	61
virtual space vector modulation (VSVM)	0.02	193	82	65

CM	3rd	fs	2fs	3fs
SPWM	0.43	237	66	51
SVPWM	61	225	40	90
THIPWM	49	228	47	87
SVM	61	225	40	90
SVM_RCM1	61	20	40	61
VSVM	0.02	27	65	65

PFC(AC-DC)

Grid Side and Common Mode inductors

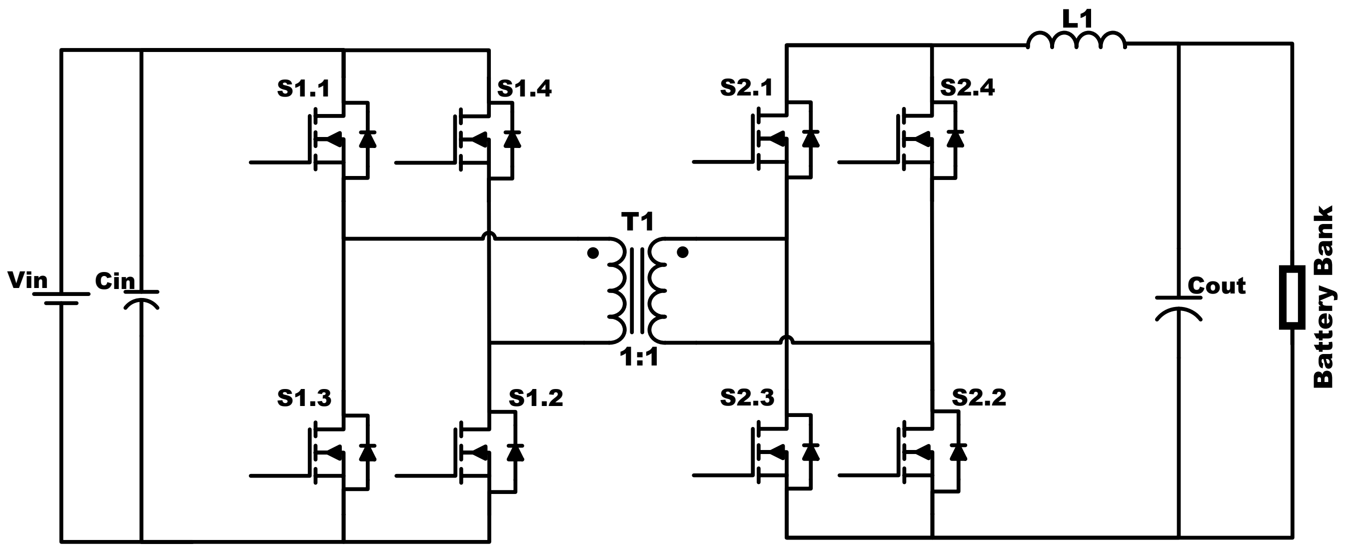
Modulation technique	Grid side inductor	Common mode inductor
SPWM	98μH	681μH
SVPWM	117μH	345μH
THIPWM	116μH	410μH
SVM	117μH	345μH
SVM_RCM1	117μH	345μH
VSVM	99μH	663μH

Future plan

- Finishing the experimental tests
- Finishing the EMI measurements

Isolated dc-dc converter

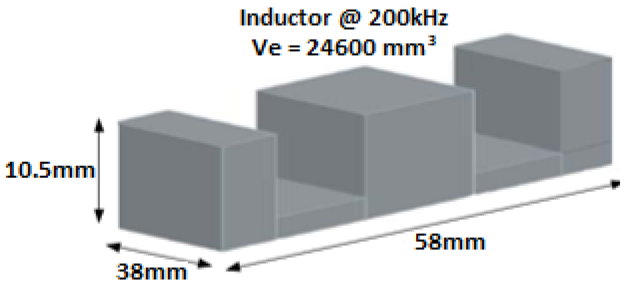
Description	Value
Output power	20kW
Input voltage	700V
Battery bank voltage	350-700V
Switching frequency	100 kHz

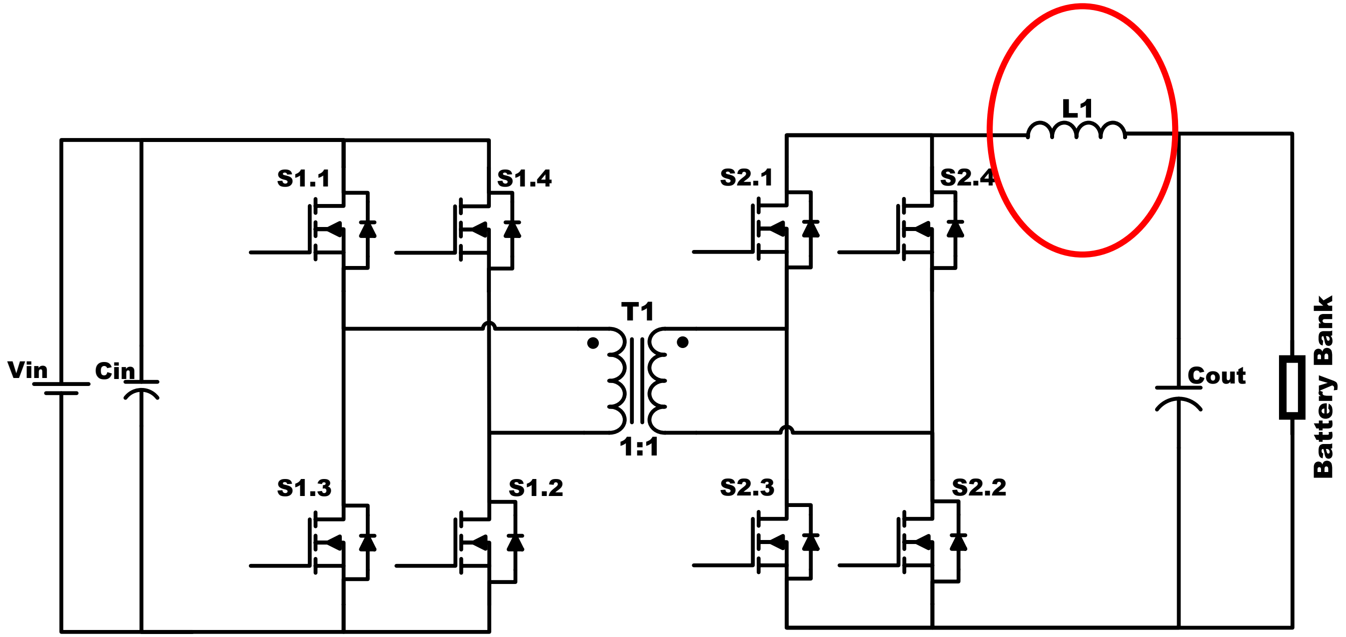


20 kW inductor

20 kW, 200 kHz Inductor

- Core : Magnetic FR45810EC
- Inductance: 45.40 µH
- Number of turns: 14
- Air gap: 2.15mm
- PCB windings



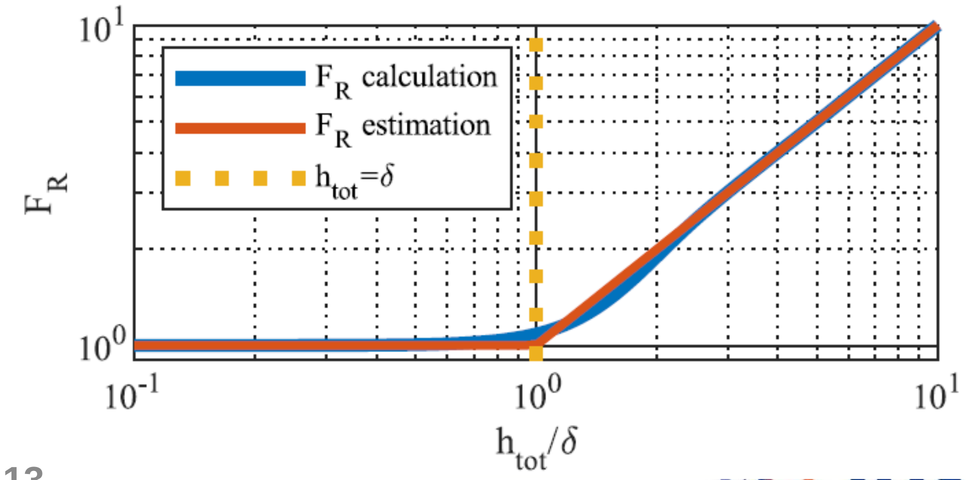


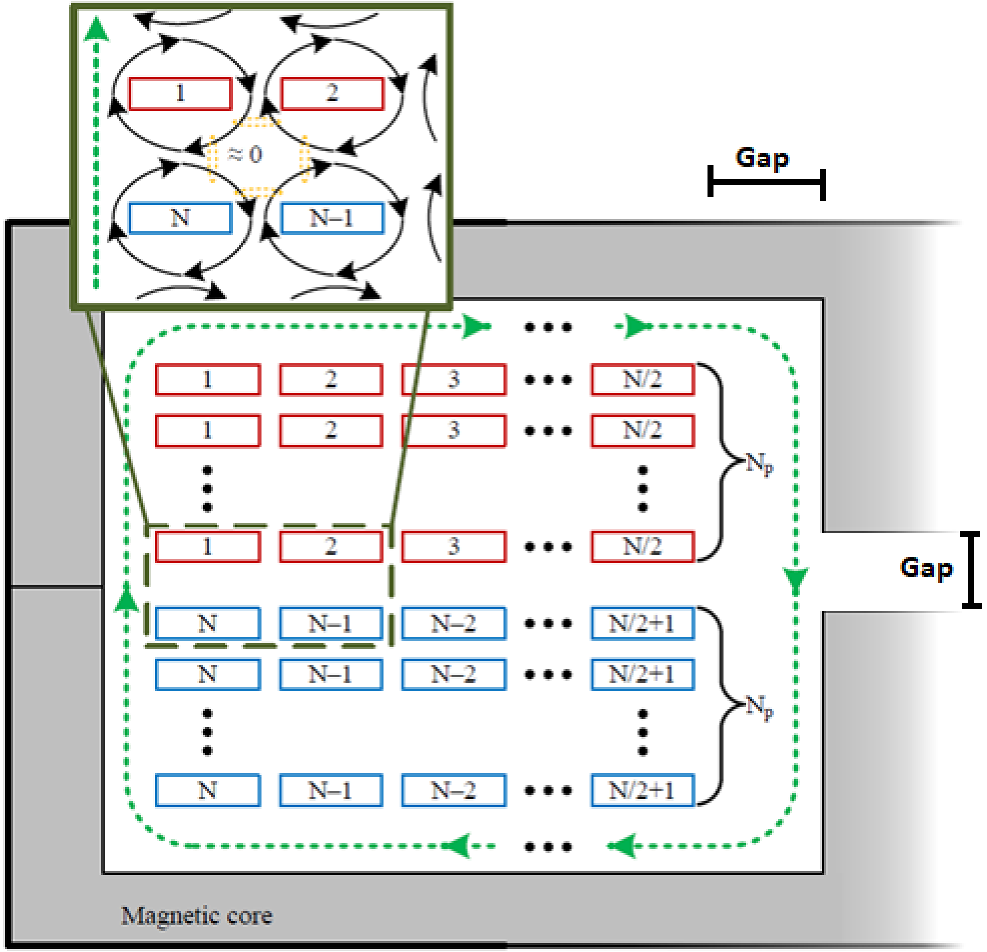
20 kW inductor

$$F_R = \frac{R_{ac}}{R_{dc}} = \varphi \frac{\sinh 2\varphi + \sin 2\varphi}{\cosh 2\varphi - \cos 2\varphi} + \frac{2(m^2-1)}{3}\varphi \frac{\sinh \varphi - \sin \varphi}{\cosh \varphi + \cos\varphi}.$$

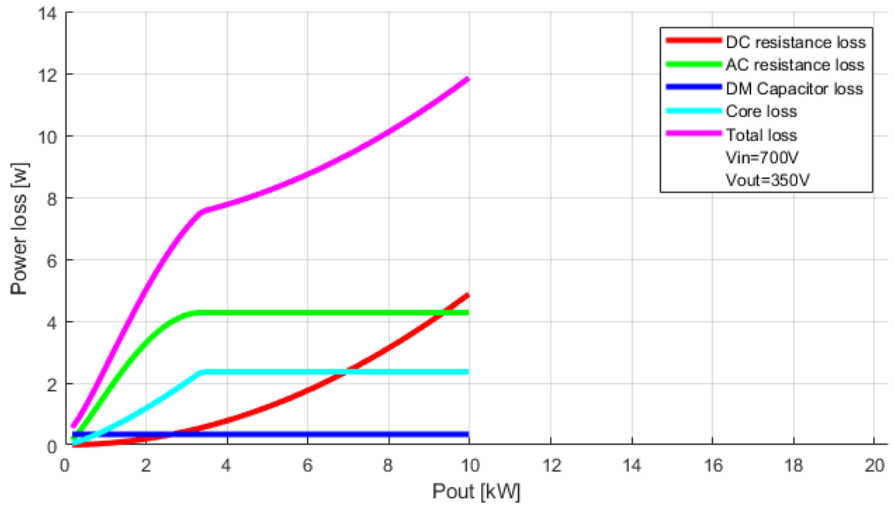
Where $\varphi = h/\delta$.

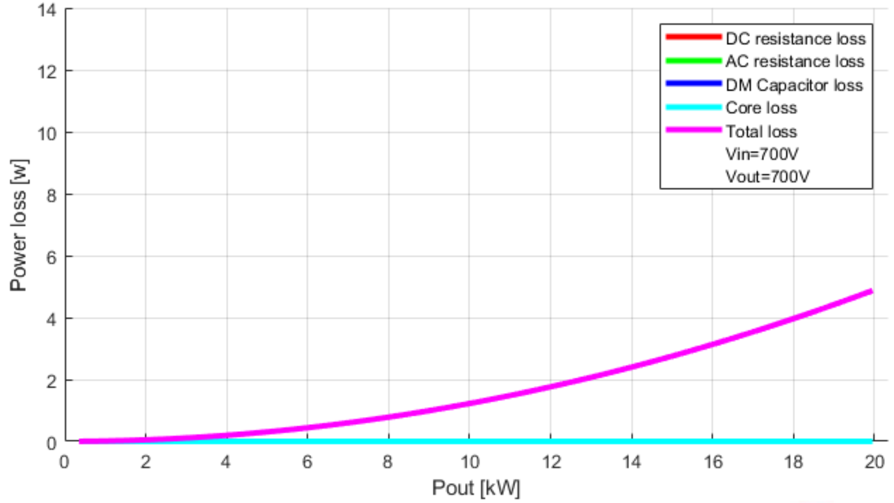
$$F_R \approx \begin{cases} \varphi = \frac{h_{tot}}{\delta} = \frac{N_p\ h}{\delta} & \text{if } \delta < N_p\ h \\ 1 & \text{otherwise} \end{cases}$$

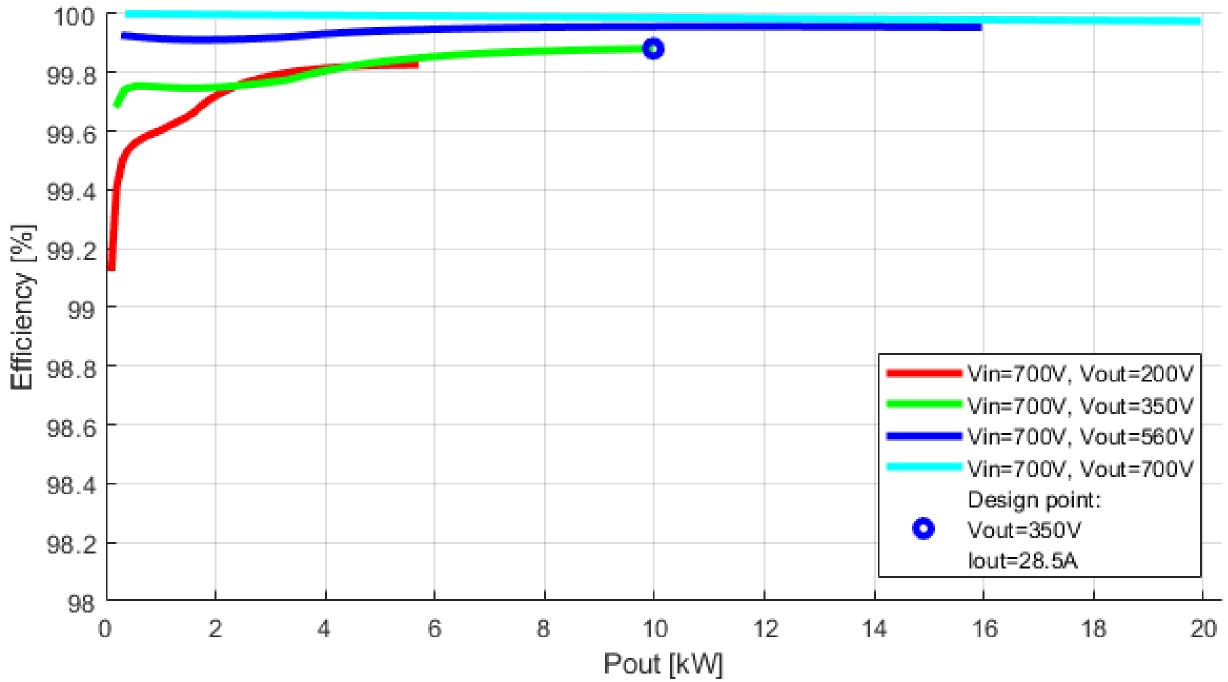




20 kW inductor



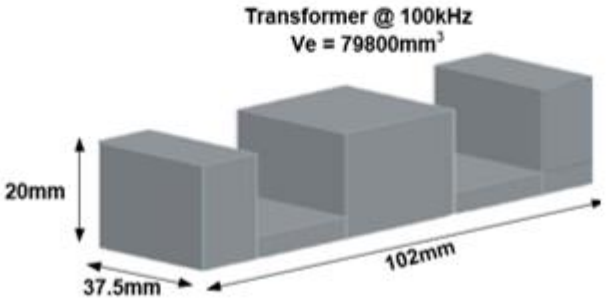


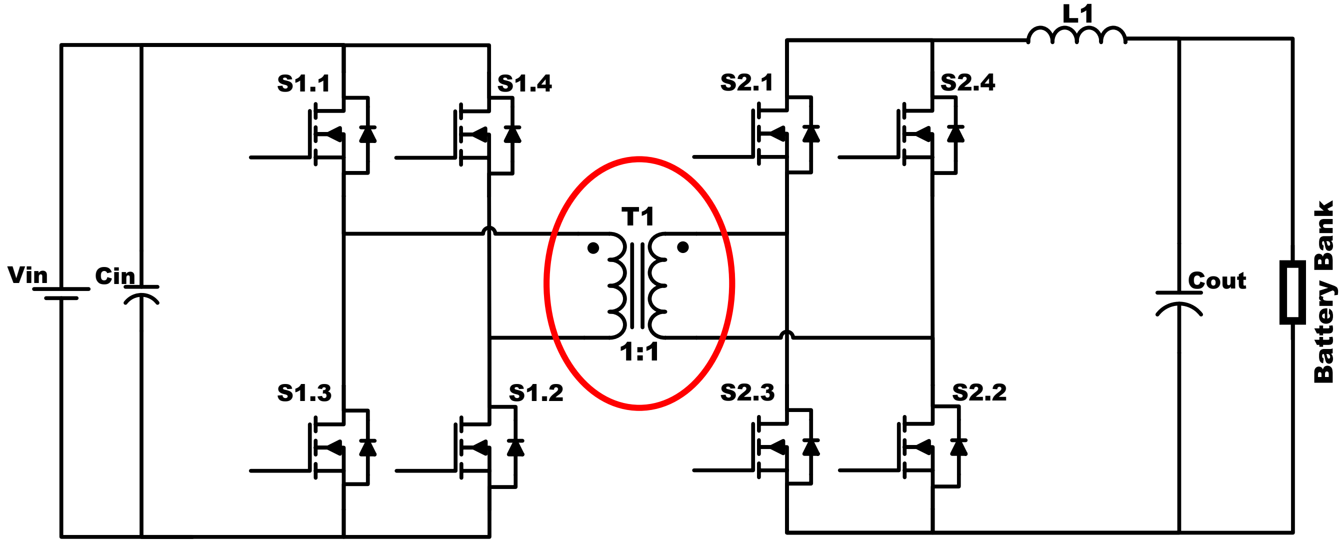


20 kW transformer

20 kW, 100 kHz Transformer

- Turns ratio : 1:1
- Number of turns: 27
- Copper foil winding
- Winding : 0.20 mm x 80 mm





20 kW transformer

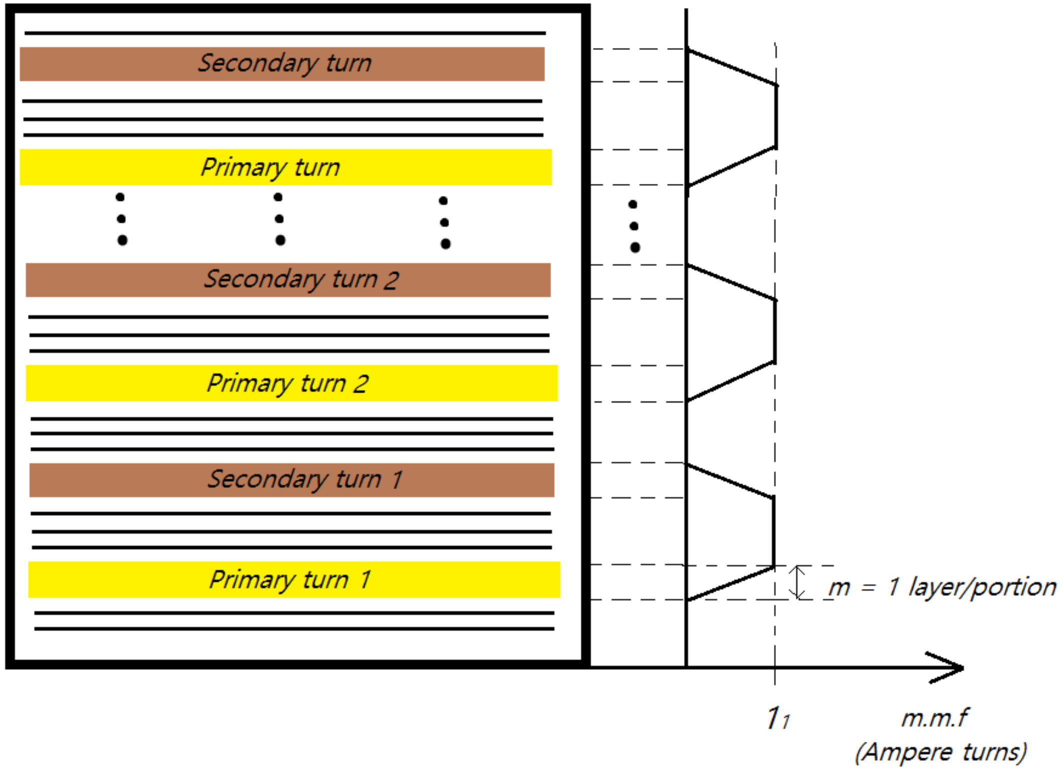
Leakage inductance:

$$L_{LK} = \mu_0 \frac{N^2 l_w}{M^2 b_w}\left(\frac{1}{3}\sum_{P=1}^{2M} h_P + \sum_{\Delta=1}^{M} h_\Delta\right)$$

Ac-resistance

$$F_R = \frac{R_{ac}}{R_{dc}} = \varphi\frac{\sinh 2\varphi + \sin 2\varphi}{\cosh 2\varphi - \cos 2\varphi} + \frac{2(m^2-1)}{3}\varphi\frac{\sinh\varphi - \sin\varphi}{\cosh\varphi + cos\varphi}.$$

Where $\varphi = h/\delta$.

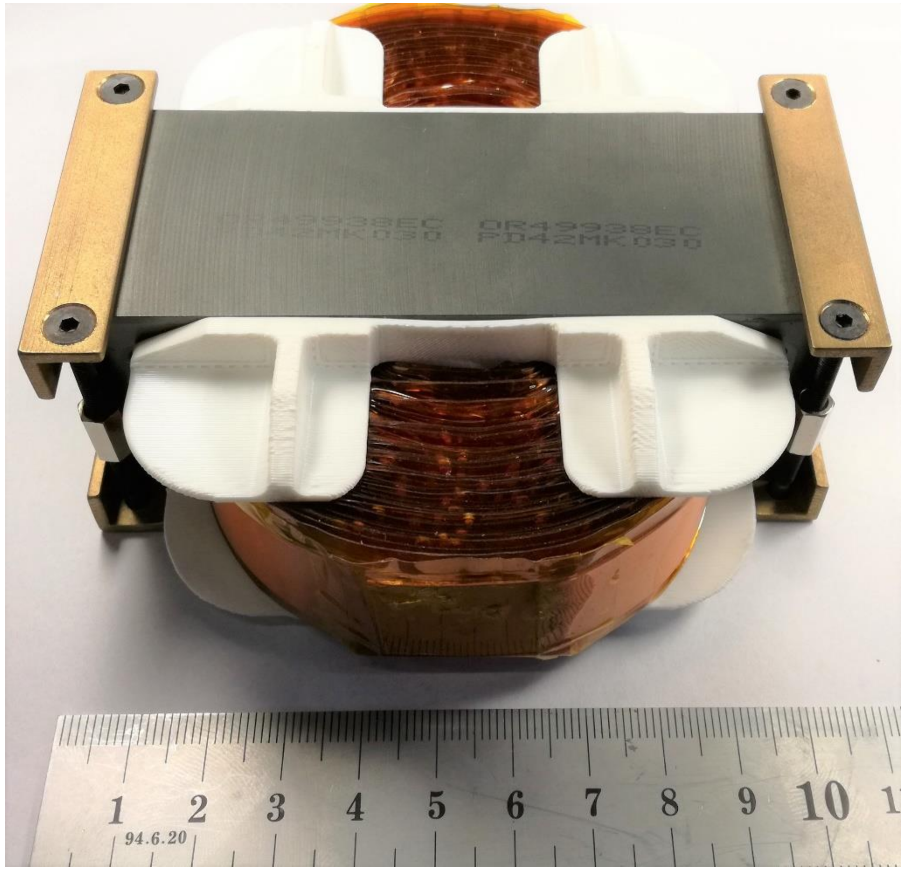


Ref: M. Nymand and M. A. E. Andersen, "High-efficiency isolated boost DC–DC converter for high-power low-voltage fuel-cell applications," IEEE Transactions on Industrial Electronics, vol. 57, no. 2, pp. 505–514, Feb. 2010.

20 kW transformer

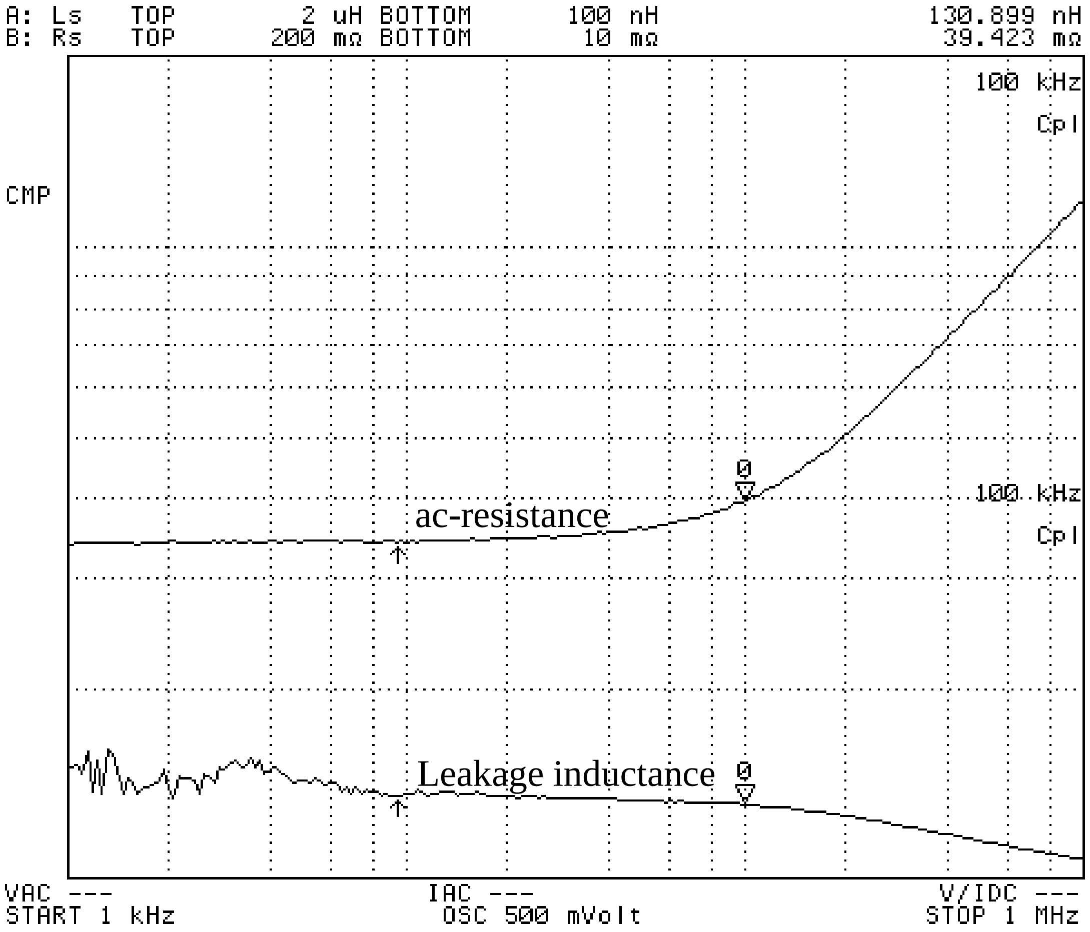
20 kW, 100 kHz Transformer

- Core : Magnetic 0R49938EC
- Turns ratio : 1:1
- Number of turns: 27
- Core loss: 11.5W
- Copper loss: 34.7W
- Efficiency: 99.77%



20 kW transformer

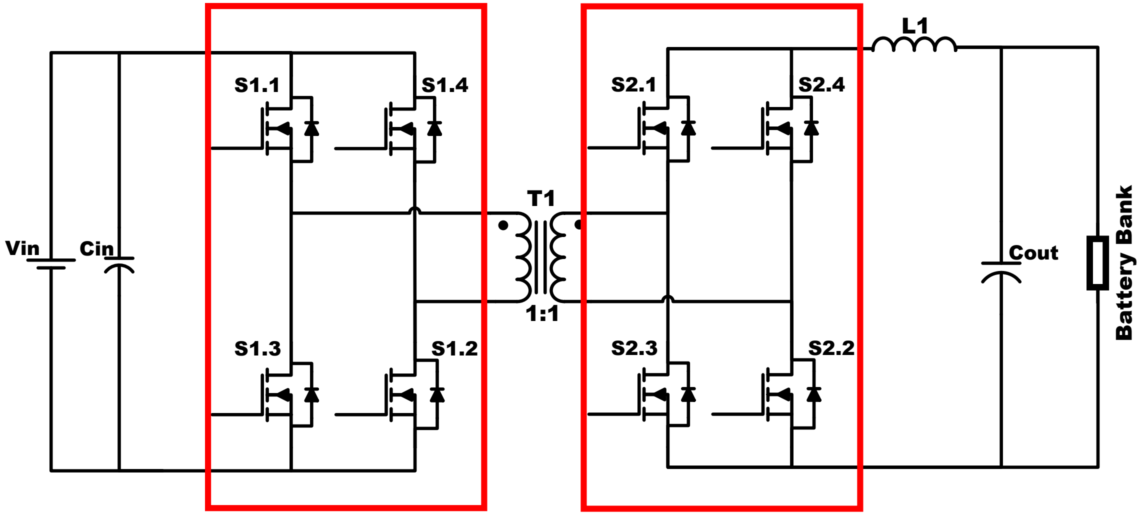
Parameters	Calculated	Measured
Leakage inductance, L_{lk}	77.5nH	130.9nH
dc-resistance, R_{dc}	27.09mΩ	33.84mΩ
ac-resistance, R_{ac}	29.26mΩ	39.42mΩ
Resistance factor, F_R	1.08	1.16

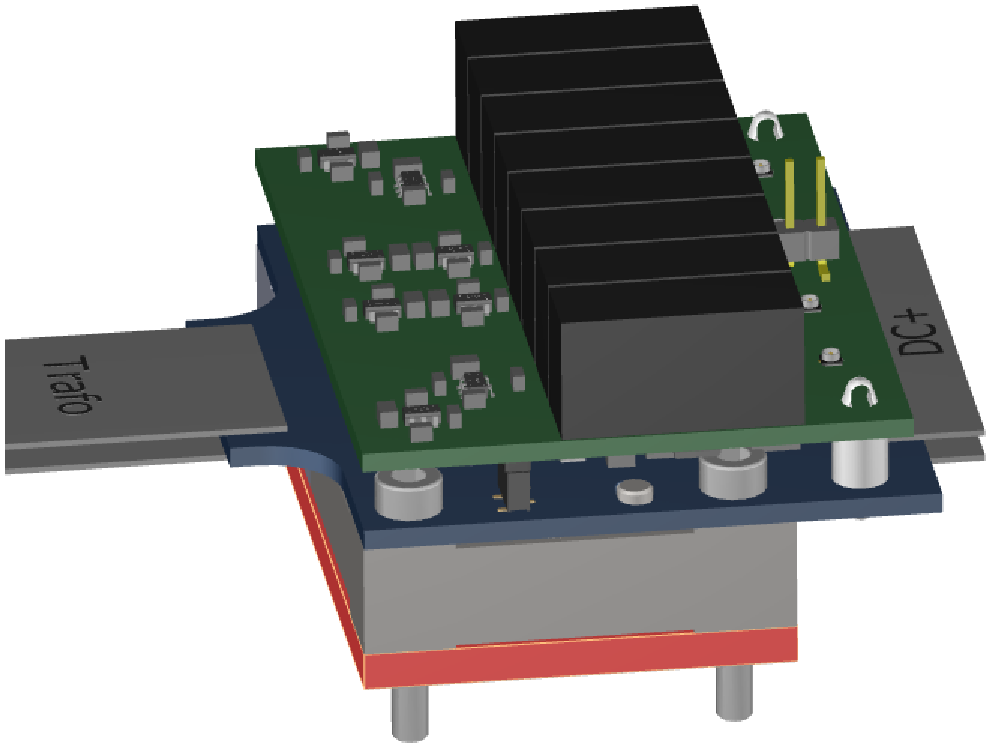


Power module

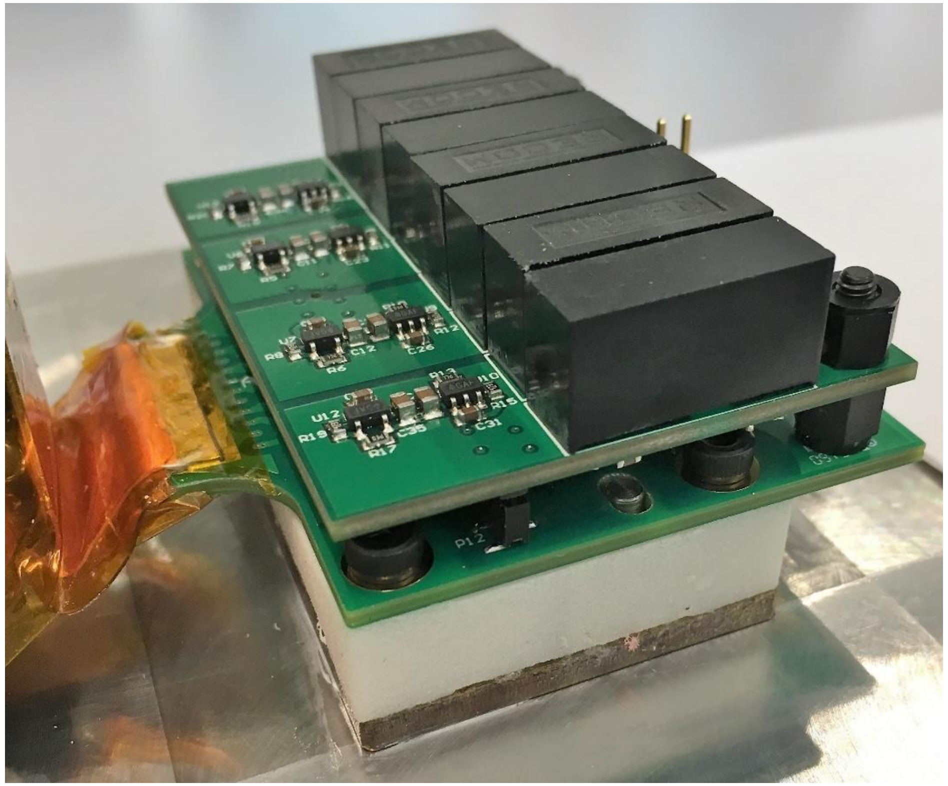
Power module from FH-Kiel

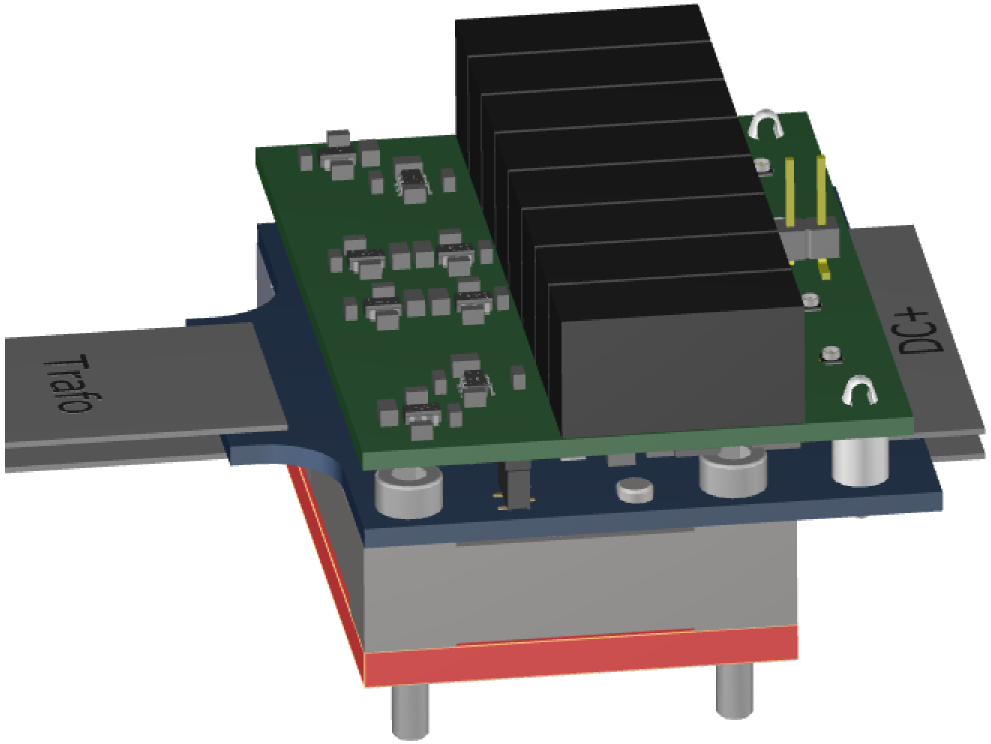
- Integration of power module with the drive circuit





Hardware prototype





Future plan

- Testing of the power module unit
- Prototyping of the planar inductor
- Realization of the converter and testing

Prospects

- A high efficiency battery charger can be used for fast-charging and vehicle-to-grid charging
- Achieving highest conversion efficiency is the key parameter, since it reduces system size and cost, while increasing system reliability
- Electrification of professional working machines, off-highway vehicles, ferries, etc.

Publications (2019)

- M. Najjar, A. Kouchaki, and M. Nymand, “An Efficient Active Common Mode Filter: Comparison of Feedback and Feedforward Based Methods for a 20 kW 3-phase Inverter” 2019 13th IEEE International Conference on Compatibility, Power Electronics, and Power Engineering(CPE-POWERENG-2019), Sønderborg, 2019.
- M. Najjar, A. Kouchaki, and M. Nymand, “Evaluation of Active Common Mode Filter Utilization for Size Optimization of a 20 kW Power Factor Correction” 2019 13th IEEE International Conference on Compatibility, Power Electronics, and Power Engineering(CPE-POWERENG-2019), Sønderborg, 2019.
- C. Kjeldsen, C. Østergaard, M. Nymand, and R. Ramachandran, “Procedure to Compare Different Design Methods for Implementation- Ready High Power Inductors”, 2019 13th IEEE International Conference on Compatibility, Power Electronics, and Power Engineering(CPE-POWERENG-2019), Sønderborg, 2019.

Thank you very much for your attention

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