FLEXINet
Result 2

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FLEXINet Workshop 2

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Scope

- **Reducing fossil fuel usage** is the most critical step that we can take to address **global warming**.
- The Netherlands took the initiative to reduce fossil fuel by **moving away from natural gas**
- Additionally, it is expecting 100% **zero emissions by 2030**.
- However, these initiatives in reducing fossils will create pressure on the power grid to meet the **growing demands** in the years to come.
- A smart combination of battery chargers, PV panels, and EV chargers with multiport converters can help us to **reduce** the home's peak **power consumption** and **pressure on the grid**.

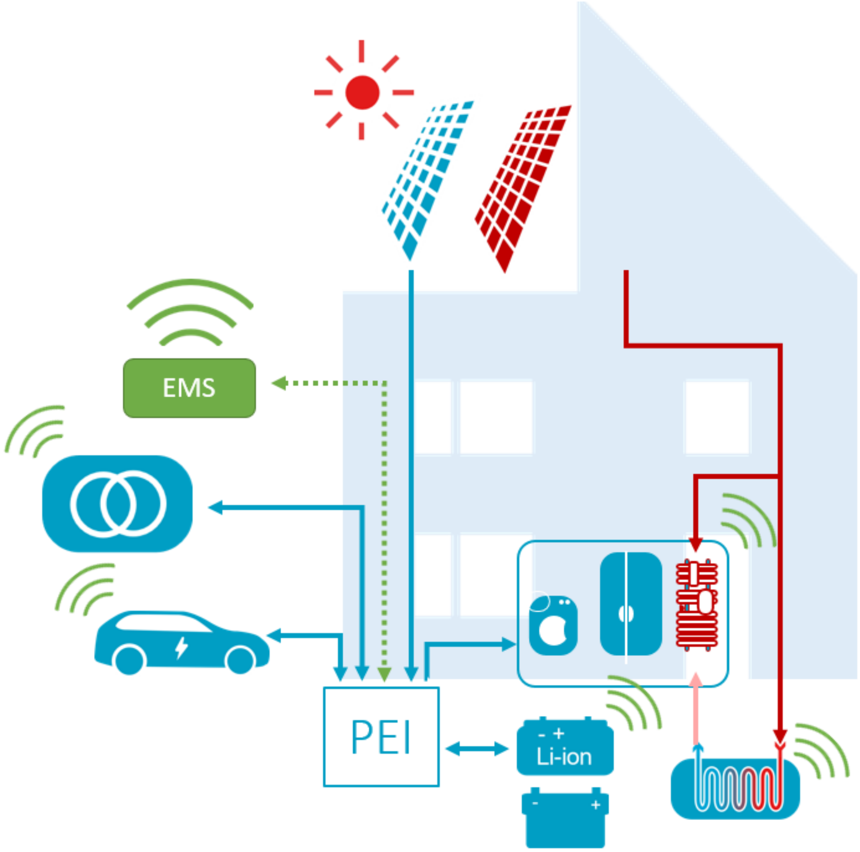


Figure 1: FLEXINet system

Motivation

- PEI- Power electronics Interface
- PEI is a multiport converter, consisting of:

  1. Electric Vehicle DC charger
  2. Grid-connected Inverter
  3. Li-ion DC-DC Battery charger
  4. PV DCDC converter

- Estimate space occupied by PEI unit: **0.5m * 2m *1m**
- PEI is bulky and occupies substantial space for residential use.
- To save space, **PEI can be placed underground** with batteries and a heat pump.

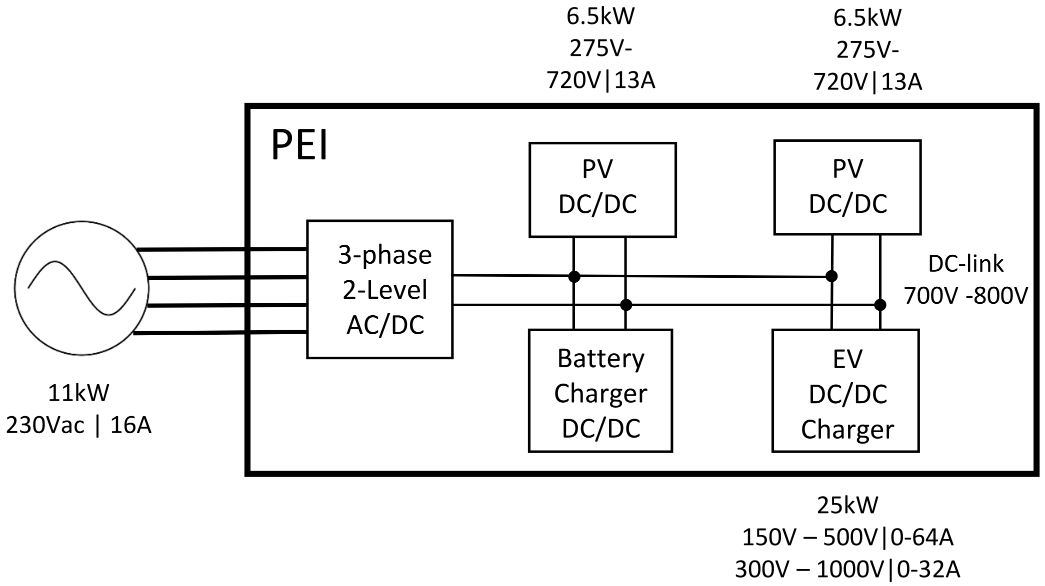


Figure 2: Power Electronics Interface

Challenges

- PEI will be placed 60 cm under the surface of the earth.
- **Forced air convection** cooling using fans is one of the **cheap** and mainstream solutions to cool power converters.
- Unfortunately, forced air convection cooling cannot be applied for underground power electronics because **no air ventilation** in the enclosed space.
- The other form of cooling – liquid convection cooling requires a pump and heat exchanger and is a comparatively expensive solution.

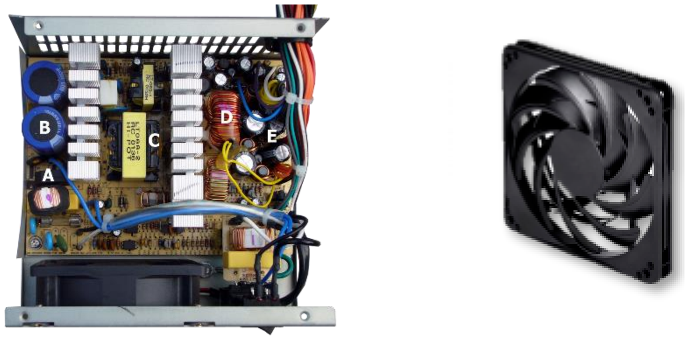


Figure 3a: Forced air convection cooling [5]

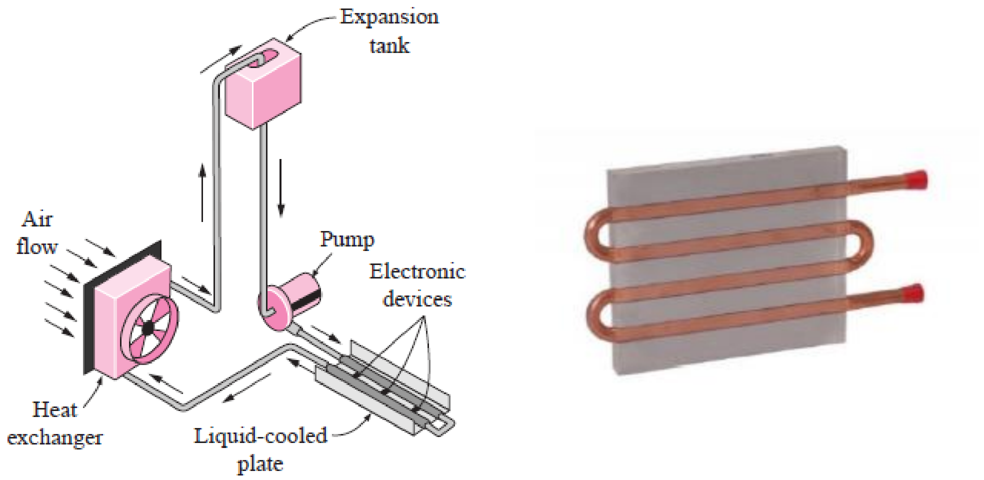


Figure 3b: Forced liquid convection cooling [5][4]

[5] https://en.wikipedia.org/wiki/Power_electronics
[4] Heat and Mass Transfer A Practical Approach, 3rd Edition by Cengel. (n.d.).

Research

- Research focuses on making PEI **operate efficiently** when placed in sub-surface soil.
- **Electric Vehicle – DCDC charger** is researched for underground application.
- The thermal management solution and converter level design solution then **can be scaled** for the rest of the converters in PEI.

Parameters	**Quantities**
Output power	25 kW
Output voltage	150-500 Vdc / 300-1000 Vdc
Output current	0-32 Adc / 0-16Adc
Input voltage	700-800 Vdc

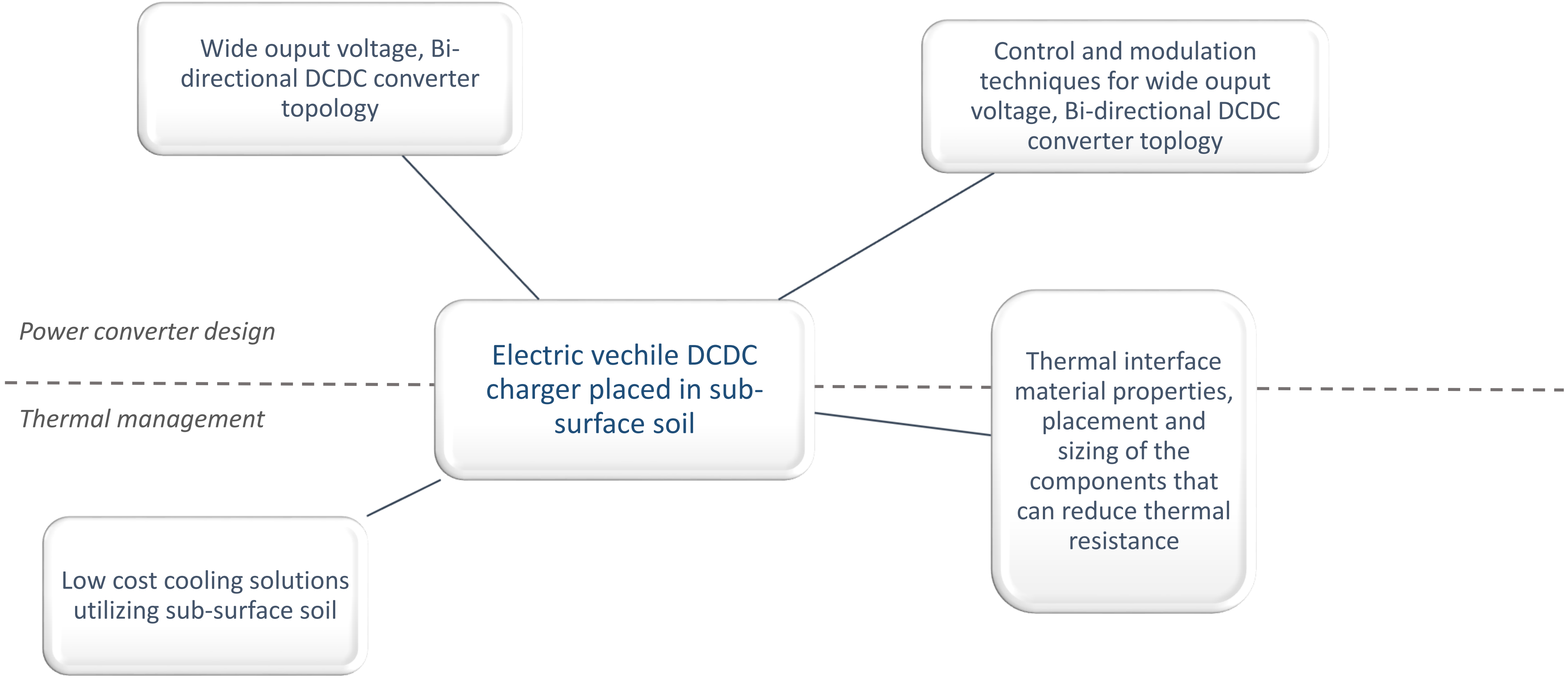
Table 1: Specification of the converter

- Application specific requirements
  - Bi-directional DCDC converter for EV charging and V2G.
  - Wide output voltage requirement for charging discharging 400V and 800V EV batteries.

Soft-switching or resonant converters:

1. Dual Active Bridge converter
2. CLLC converter

Research direction



Wide ouput voltage, Bi-directional DCDC converter topology

Control and modulation techniques for wide ouput voltage, Bi-directional DCDC converter toplogy

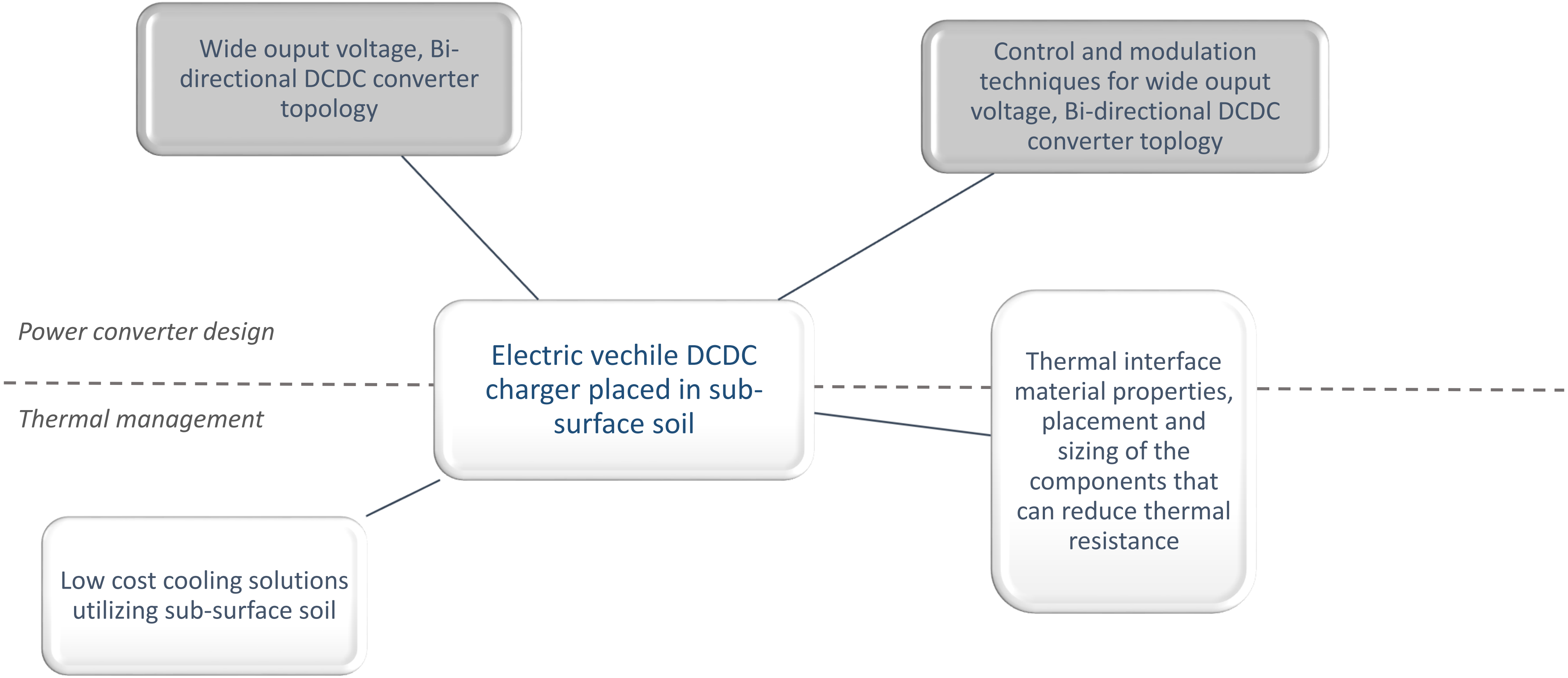
Power converter design

Thermal management

Electric vechile DCDC charger placed in sub-surface soil

Thermal interface material properties, placement and sizing of the components that can reduce thermal resistance

Low cost cooling solutions utilizing sub-surface soil



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Topology for EV charger DCDC converter

- 2- module DAB converter.
- The output voltage of each module can be connected in series/parallel to charge 800V and 400V EV battery packs.
- The input voltage (V_g) is the DC link voltage from the three-phase grid-connected inverter.
- DAB converter has symmetric characteristics for both forward and reverse power flow.

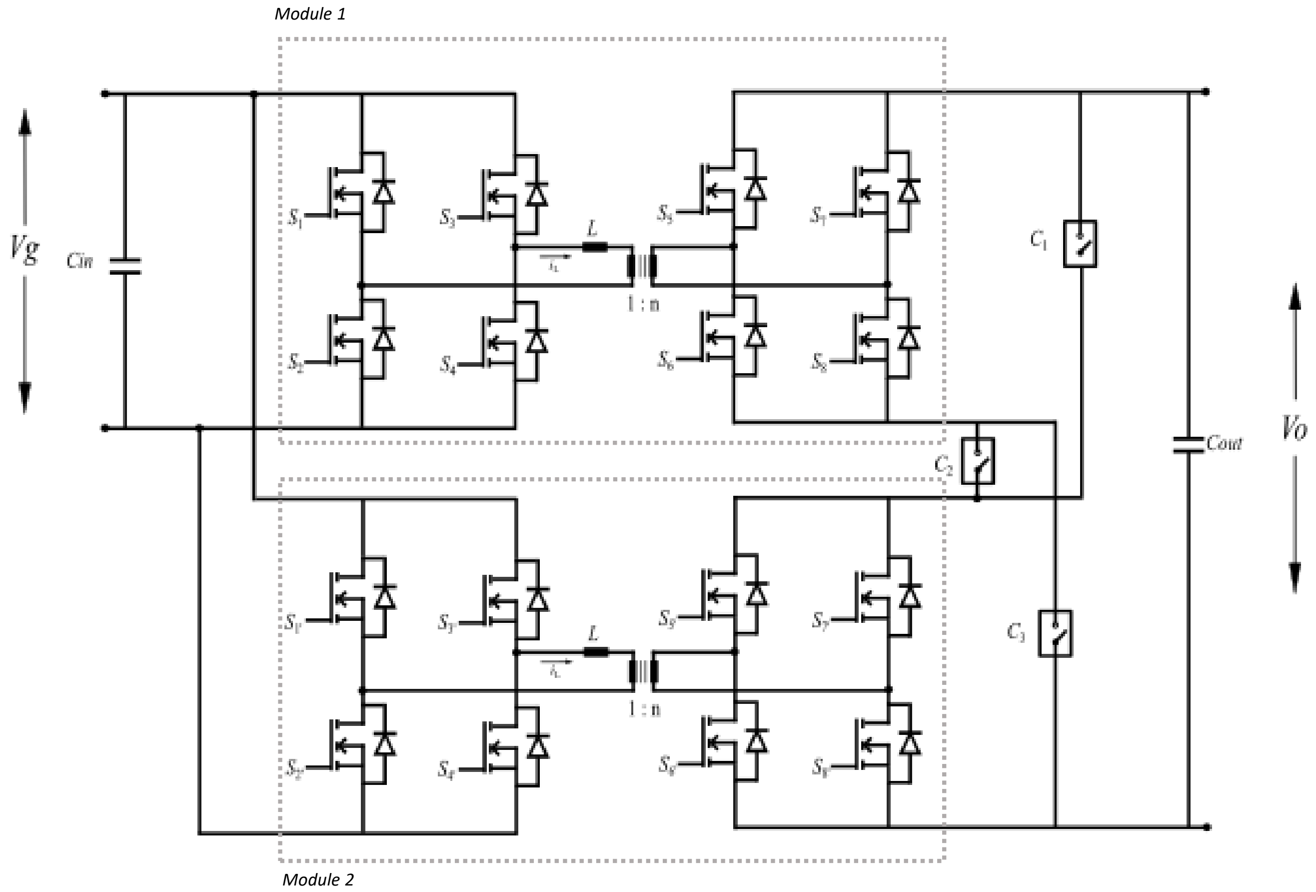

Figure 4: Parallel input and series/parallel output Dual Active Bridge converter

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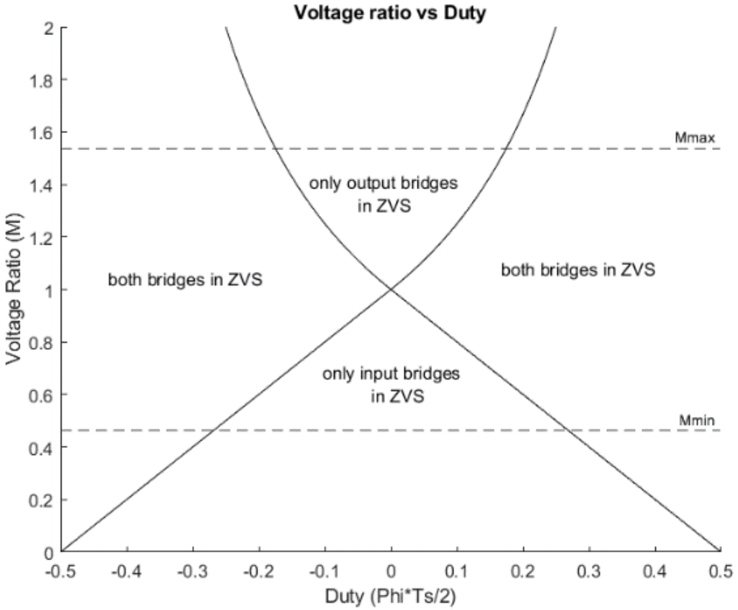
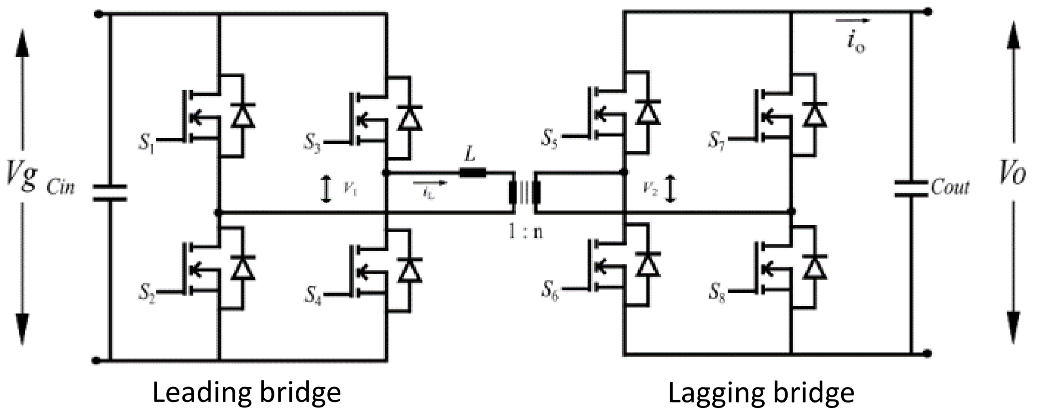
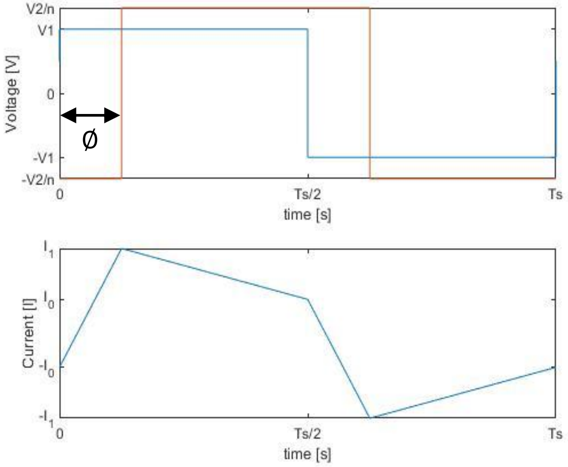


Figure 5: conversion ratio vs duty cycle of DAB

Topology for EV charger DCDC converter





$$I_1 = i(t_1) = \frac{V_g}{4.f_s.L}[(2D-1)+M]$$

$$I_0 = i(t_0) = \frac{V_g}{4.f_s.L}[1+(2D-1)M]$$

$$Voltage\ Ratio\ (M) = \frac{V_o}{n.V_g}$$

$$\text{Duty (D)} = \frac{\emptyset}{\text{Ts / 2}}$$

∅ is a phase shift between V_1 and V_2

Figure 6: 1-module DAB converter circuit, inductor current, and full bridge voltage waveforms with single phase shift control

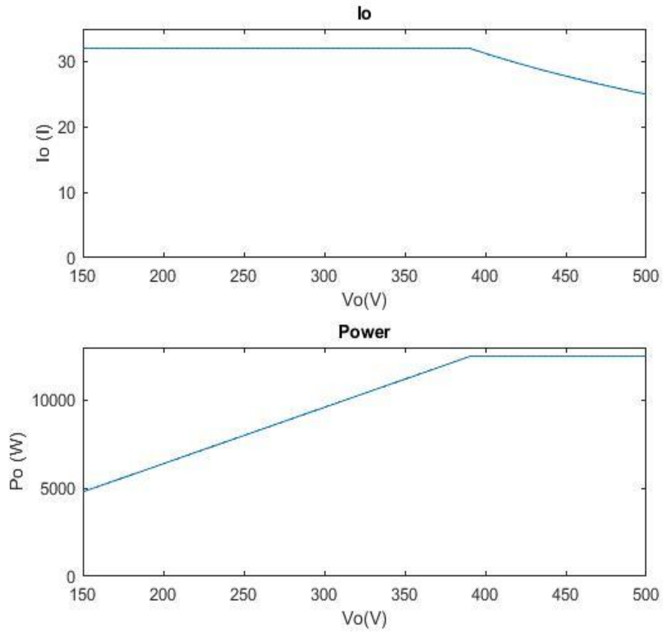


Figure 7: Output power and current limit of the 1 module DAB

Parameters	Quantities
Output power	12.5 kW
Output voltage	150-500 Vdc
Output current	0-32 Adc
Input voltage	700-800 Vdc

Table 2: specification of 1 module DAB converter

Output characteristics, RMS current and Reactive power

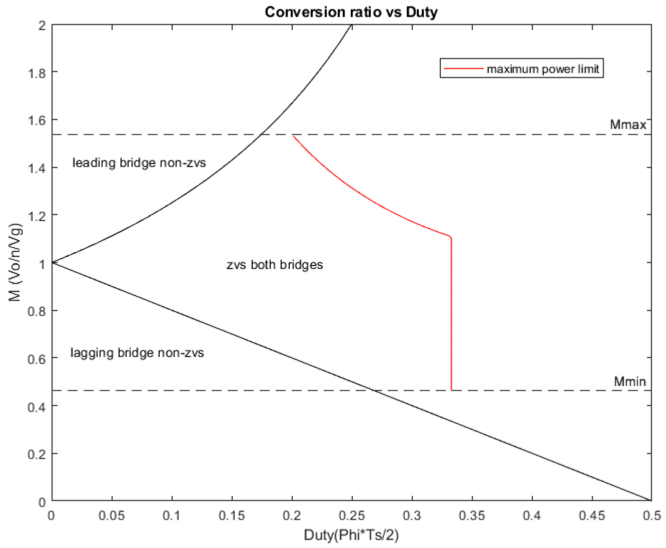


Figure 8: conversion ratio vs duty cycle of DAB

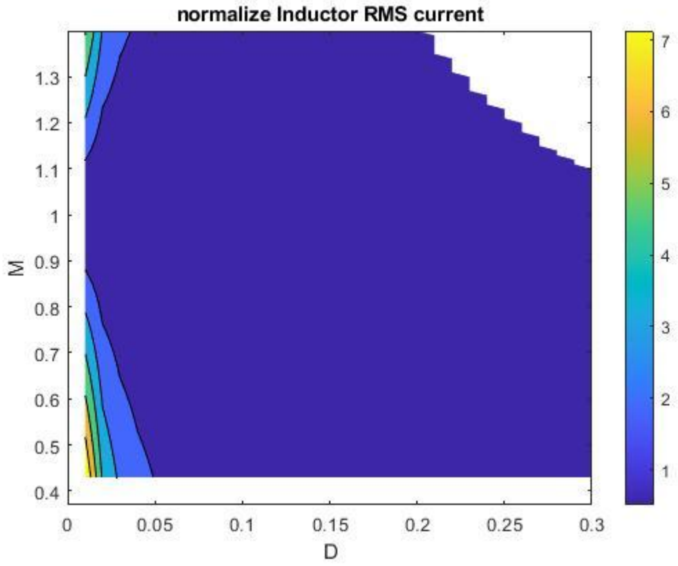


Figure 9: Normalize RMS current of DAB

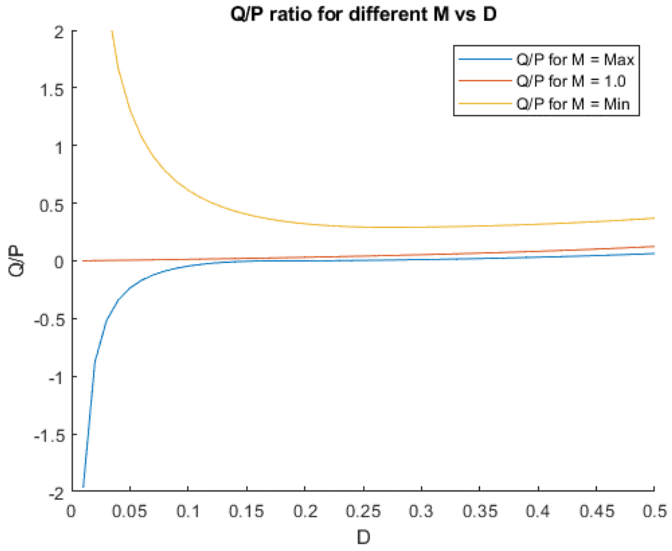


Figure 10: Reactive power at different voltage gains w.r.t phase shifts

Phase shift control is easy to implement. Output power magnitude and direction can be controlled by controlling the phase shift between the primary and secondary bridge.

When $M \neq 1$, reactive current, and RMS current increase and there is a loss of ZVS under partial load conditions

Optimal Design for DAB

DAB needs to be designed such that it can achieve maximum ZVS range, less circulating current, and small RMS current.

The value of **L (inductor)** and **n (Turns ratio)** can be optimized to achieve maximum average efficiency

Optimization is performed based on the following considerations:

1. Maximum Duty cycle D_{max}
2. Maximum output current $I_{0\ max}$
3. Nominal input voltage V_g
4. Switching frequency 100 kHz f_{sw}
5. Single phase shift control.

$$L = \frac{V_g . D_{max} . (1 - D_{max})}{2. n. I_{o\ max} . f_s}$$

Loss calculation is based on:

1. Switches conduction losses and switching losses
2. Inductor core losses and copper loss
3. Transformer core loss and copper loss

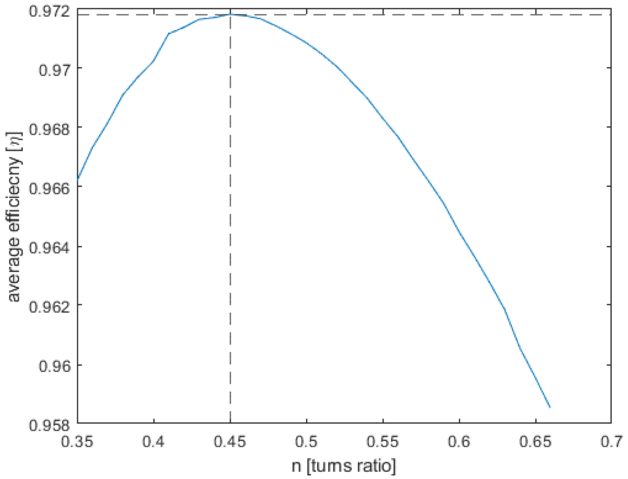


Figure 11 : sweeping of turns ratio ‘n’ to find the maximum average efficiency

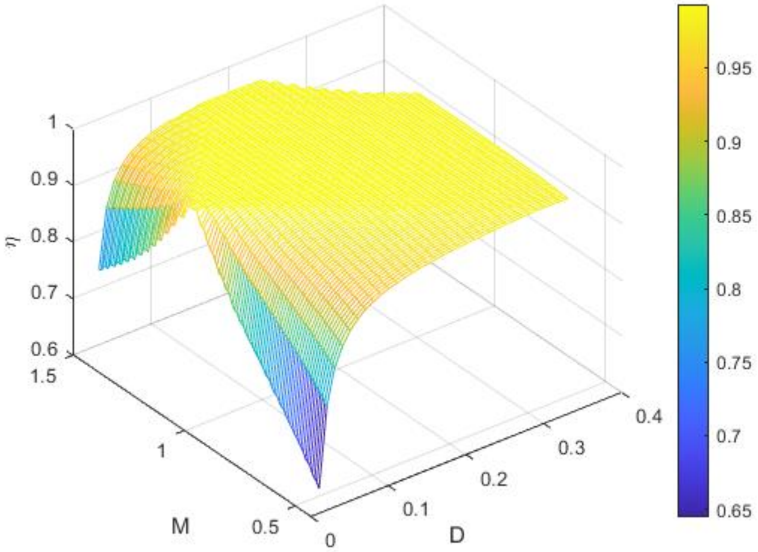


Figure 12: Efficiency for different values of D and M

Switching Frequency

The optimization process is repeated at different switching frequencies.

The switching frequency is chosen as 100kHz to obtain 97.56% average efficiency with good power density.

The **switching loss** and **core loss** are the major types of loss and therefore the research focuses on:

- **Modification in DAB hardware to improve ZVS range**
- **Modification in DAB control to reduce overall losses**

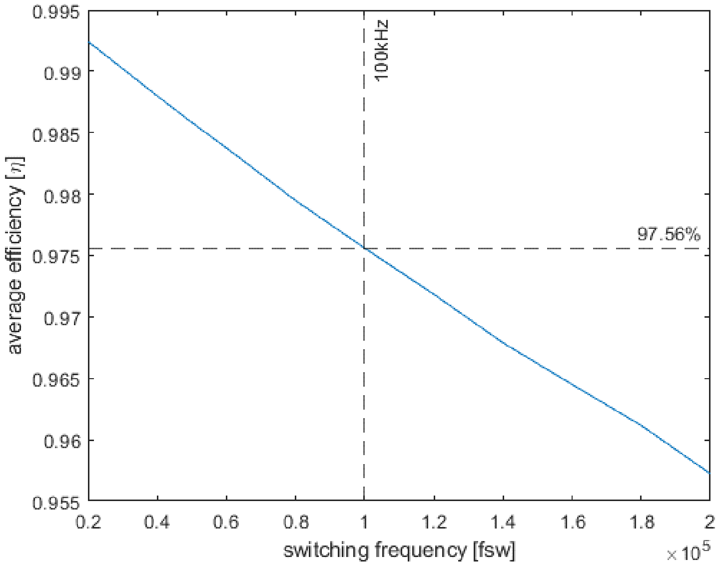
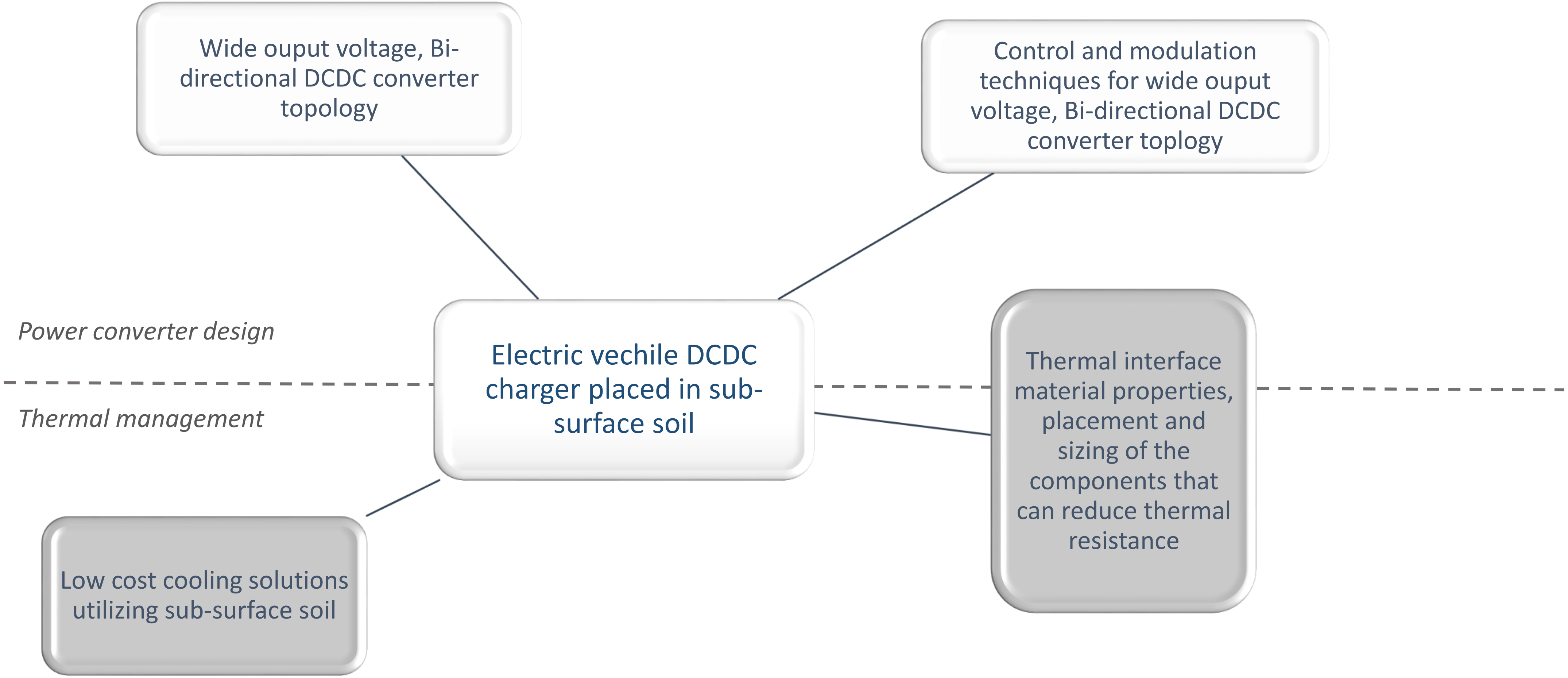


Figure 13: Efficiency vs switching frequency



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Electric vechile DCDC charger placed in sub-surface soil

Thermal management

Thermal interface material properties, placement and sizing of the components that can reduce thermal resistance

Low cost cooling solutions utilizing sub-surface soil

Thermal Management

- For a 25kW high-power density converter, the heat flux will be high.
- To limit the **junction temperature** of the SiC switch to much lower than **200 C**, and limit the temperature of magnetics below the **curie temperatures**, **Liquid Forced convection cooling** will be utilized- using **cold plates**
- The temperature inside the closed enclosure will be maintained by **conduction cooling** – the enclosure's outer surface interface with the soil.

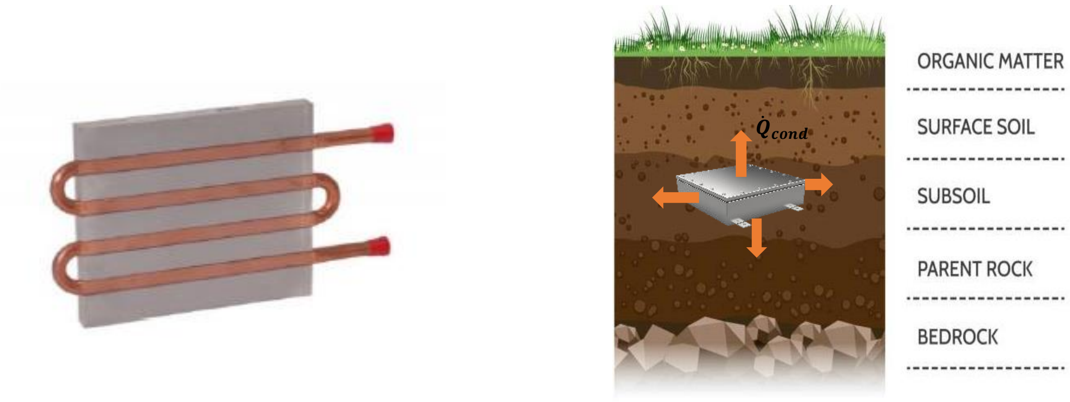

Figure 14: Cold plate for liquid forced convection and conduction cooling through the enclosure (*source- google)*

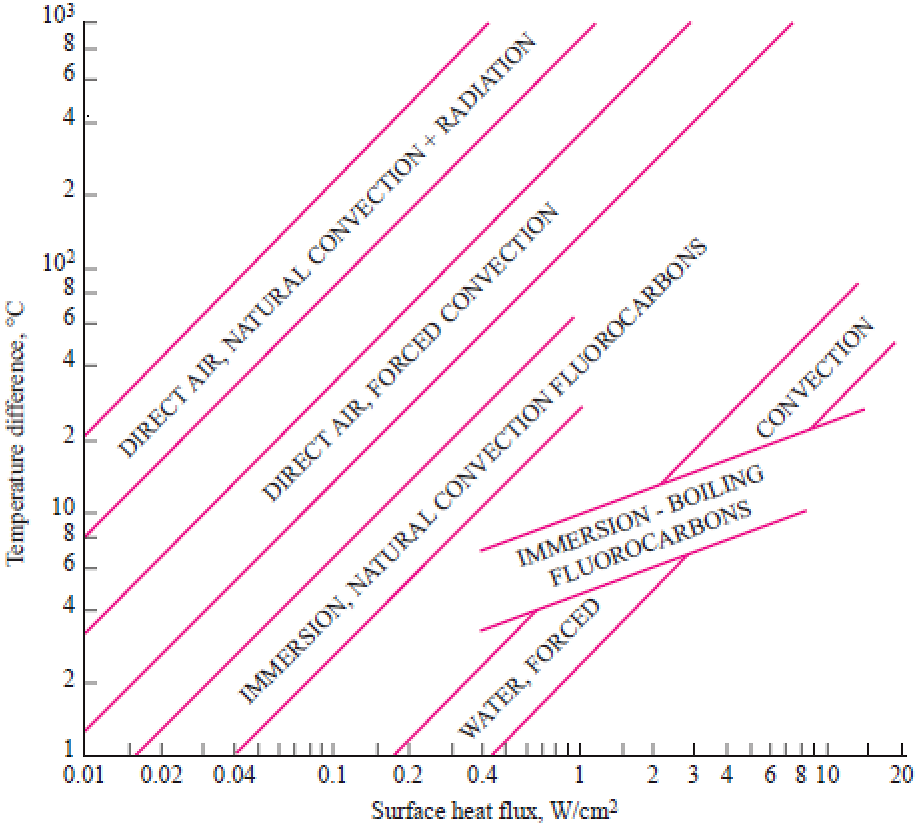

Figure 15: Heat fluxes that can be attained at specified temperature differences with various heat transfer mechanisms [4]

[4] Heat and Mass Transfer A Practical Approach, 3rd Edition by Cengel. (n.d.).

Thermal design considerations for Magnetics

- Loss in switch and losses in magnetics are dominant losses
- Cooling magnetic is not straightforward as cooling switches
- Since for a fixed voltage and current level, the overall losses in the magnetic devices usually **do not significantly drop** with an increasing frequency/decreasing volume.
- The ratio of **power loss per surface area is rising** when the power density is increased.
- This leads **to high heat flux** in the magnetic devices and therefore requires **improved heat power** removal methods.

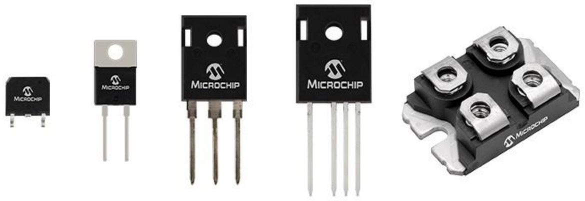

Figure 16: Silicon Carbide switches[6]

Figure 17: Inductor with round conductor and ferrite core[7]

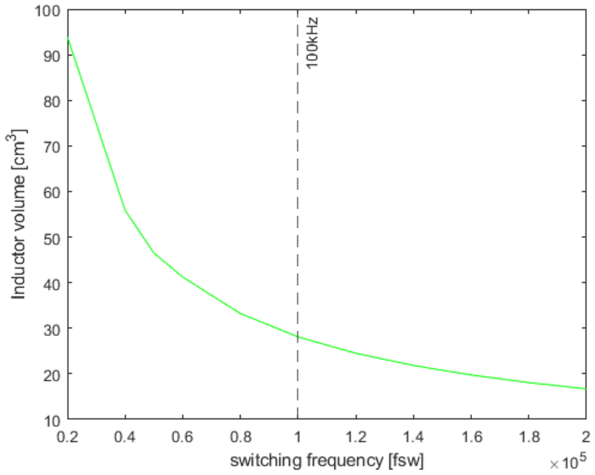

Figure 18: Volume of Inductor vs switching frequency

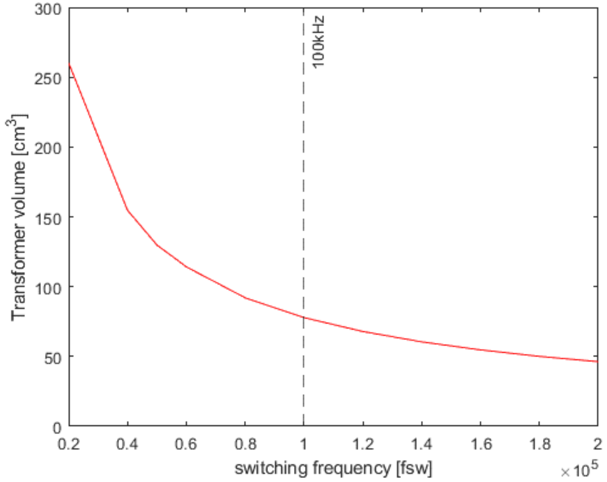

Figure 19: Volume of Transformer vs switching frequency

[6] https://www.microchip.com/en-us/products/power-management/silicon-carbide-sic-devices-and-power-modules

[7] https://www.bultraf.com/en/products/i3/1.3.-EE-Ferrite-Core-Transformers..html

Thermal design considerations for Magnetics

Different types of core shapes

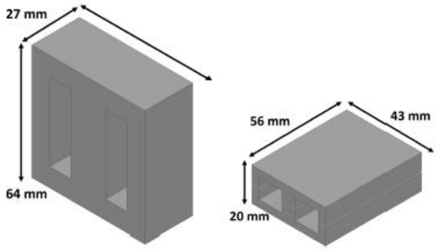

Figure 20: Standard E core E65/23/27 and Planer E core E43/10/28 [1]

Different types of core material

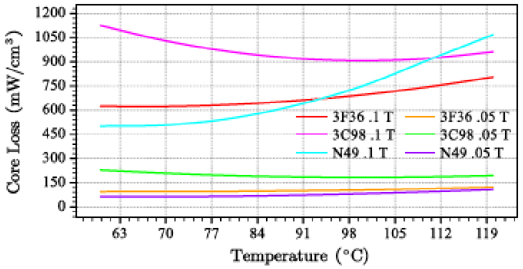

Figure 21: core loss vs Temperature for different core materials at 0.1T and 0.05T[1]

Winding geometry

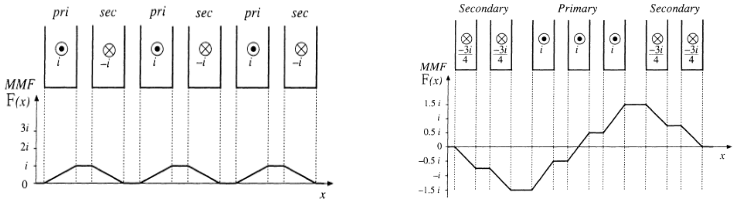

Figure 22: interleaved winding and partially interleaved winding [2]

Winding material

Figure 23: Foil winding, Litz Wire and PCB winding [1]

Paralleing cores

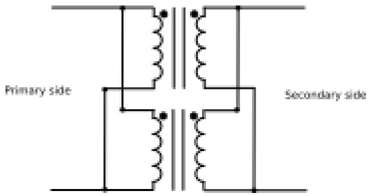

Figure 24: Two cores in Parallel [2]

Thermal Interface material

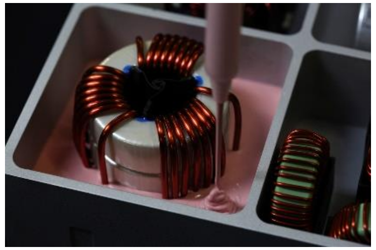

Figure 25: Potting and encapsulation of magnetics [3]

[1] Ngo, M. T. H., Dong, D., & Burgos, R. (2021). *Magnetic and Thermal Design of Litzwire 500 kHz Highpower Planar Transformers with Converging Cooling Duct for "dc Transformer" Resonant Converter Applications*.
[2] Fundamentals of Power Electronics R.W.Erikson
[3] web source: https://www.lord.com/blog/electronics/how-potting-helps-with-thermal-management

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Thank you

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Rijksdienst voor Ondernemend
Nederland

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