Application Solar & ESS

Norbert Pluschke

Semikron Hong Kong

Packaging Technology in different Application

Introduction of solar & ESS

2-level & 3-level features

3-level for ESS & Solar (ANPC)

3-level Central Converter Design

3-level Commutation Difficulties

Summery

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Introduction of solar & ESS

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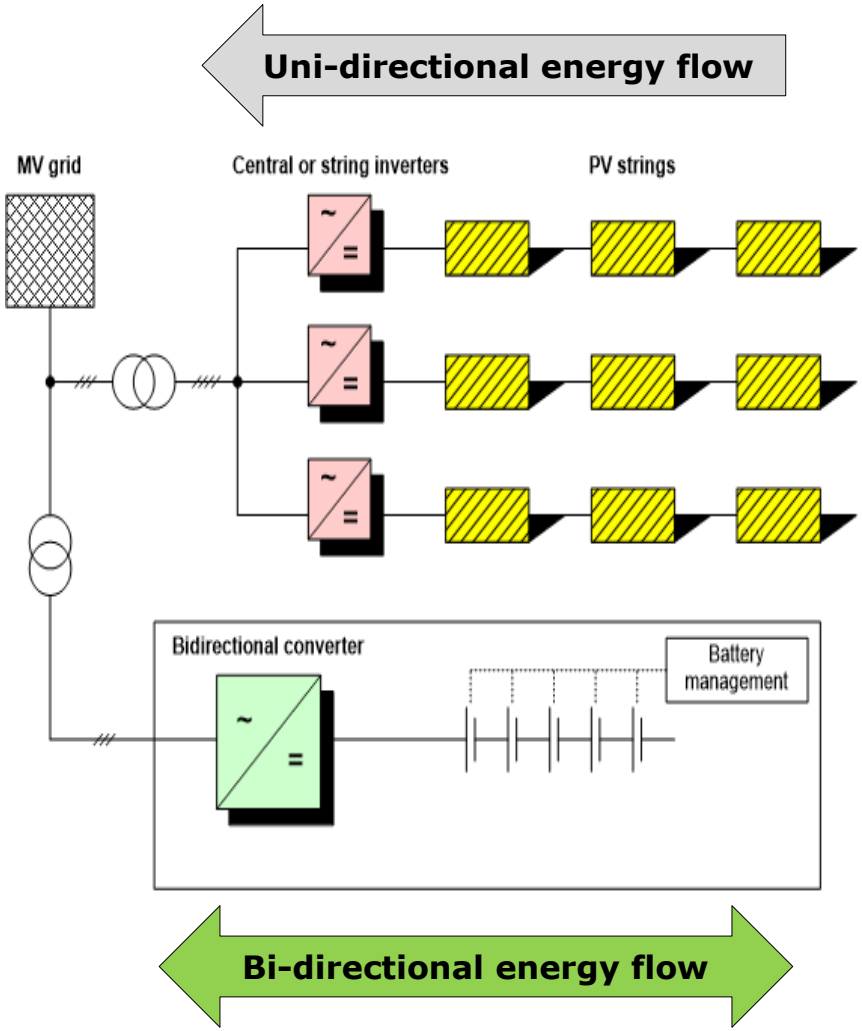
3-level Commutation Difficulties

Summery

Introduction – Solar inverter & Energy Storage Converter



String inverter

Power: x10kW - x100kW

PV string voltage:

1000V

1500V

Power conversion: DC->AC

Central inverter

Power: x100kW - xMW

PV string voltage:

1000V

1500V

Power conversion: DC->AC

Commercial ESS PCS

Power: x10kW - x100kW

Battery voltage:

600~800V（380/400VAC）

800~1100V（480VAC）

Power conversion: DC<->AC

Utility-scale ESS PCS

Power: x100kW - xMW

Battery voltage:

600~800V (380/400VAC)

800~1100V（480VAC）

1100~1500V (690VAC)

Power conversion: DC<->AC

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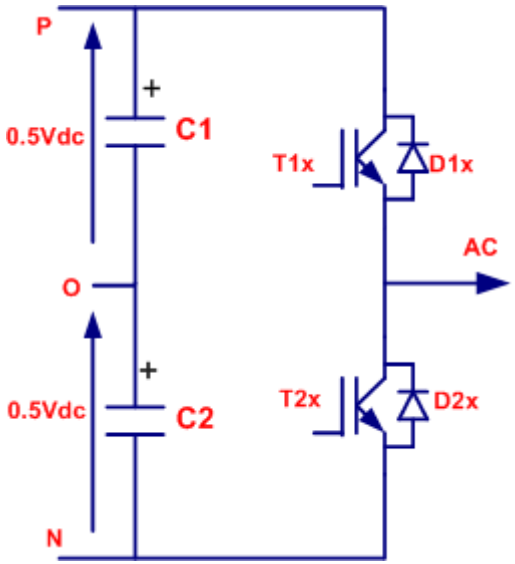
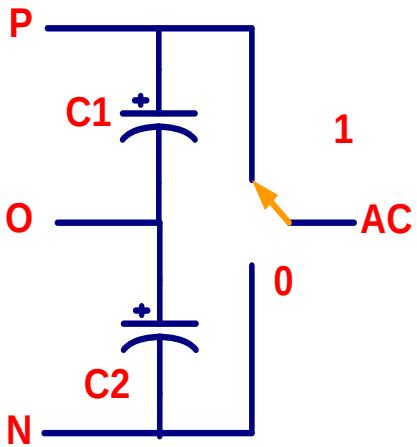
Summery

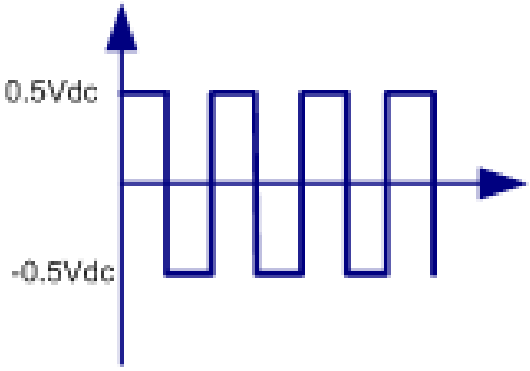
Two Level Inverter Topology

Output Voltage is of Bipolar Nature

Only Two States Per Phase







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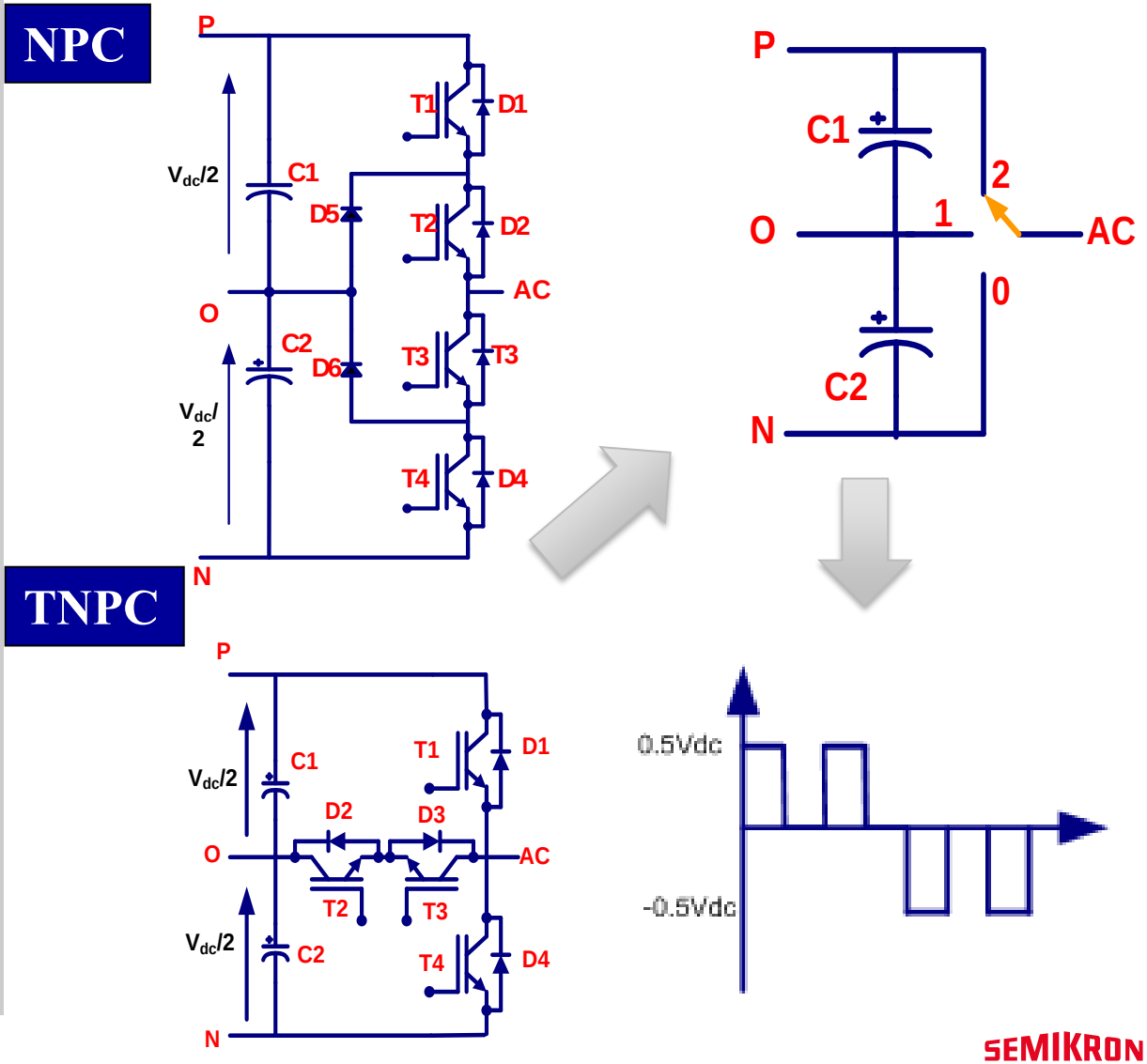
Three Level Inverter Topologies

Output Voltage is of Unipolar Nature

Three States Per Phase

Immediate Benefit: Improved Output Voltage Quality



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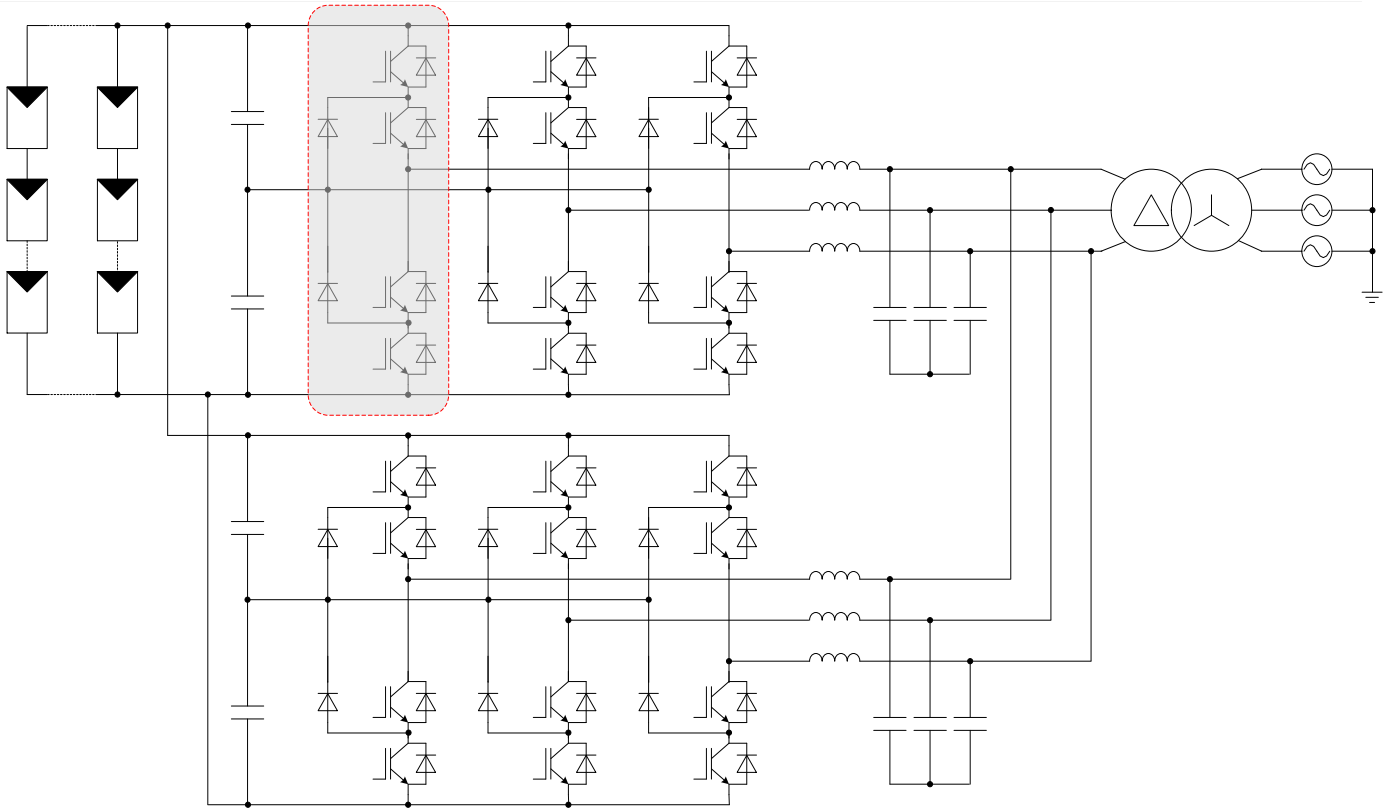
1500V DC Solar Inverter – 3 level NPC



Module available so far

- Wish is to have all devices in one module, by today up to 300A available (MLI, TMLI) commutation is in one module
- Alternative is combination of GAL, GAR and GB module

Introduction – AC/DC topologies

String inverter

Power: x10kW - x100kW

PV string voltage:

1000V

1500V

Commercial ESS PCS

Power: x10kW - x100kW

Battery voltage:

600~800V（380/400VAC）

800~1100V（480VAC）

Central inverter

Power: x100kW - xMW

PV string voltage:

1000V

1500V

Utility-scale ESS PCS

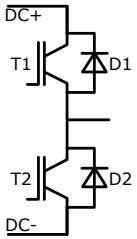
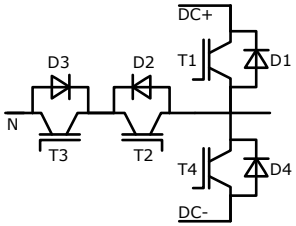
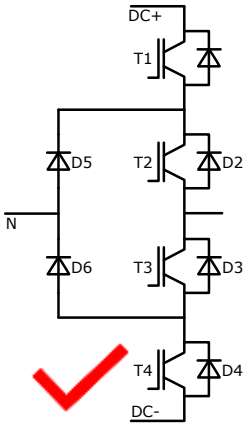
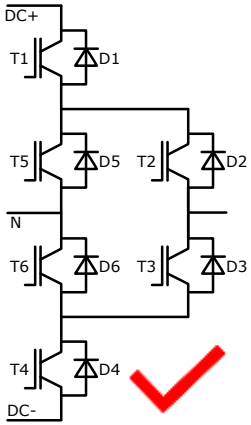
Power: x100kW - xMW

Battery voltage:

600~800V (380/400VAC)

800~1100V（480VAC）

1100~1500V (690VAC)

Topologies	2L	TNPC 3L	NPC 3L	ANPC 3L
				
1000V	1200V chip	1200V chip	650V chip	650V chip
1500V	1700V chip？	1700V chip？	950V, 1200V chips	950V, 1200V chips

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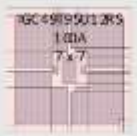
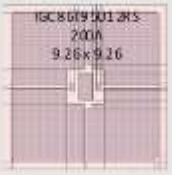
Introduction – 950V chips

950V Chip				
I_{nom} [A]	100	200	200	100
Performance	**Fast**	**Fast**	**Low V_{cesat}**	**Fast**
Dimension [mm]	7 x 7	9,26 x 9,26	9,26 x 9,26	5,42 x 5,42
Area [mm²]	49	86	86	29
Vce/Vf @150°C	2,2V	2,2V	1,35V	2,15V
Esw/100A @150°C	10,5mJ	10,5mJ	23,5mJ	2,3mJ

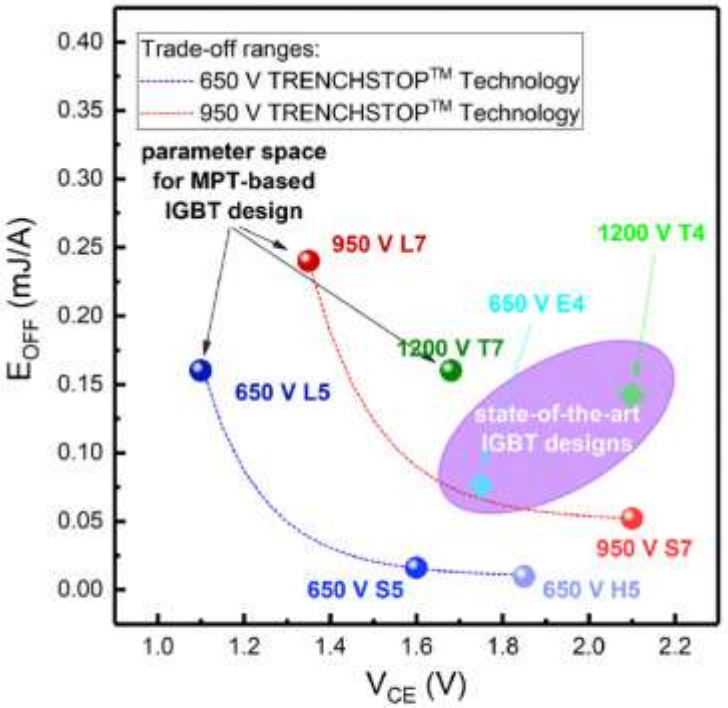


Fig. 1 Trade-off diagram of 650-V, 950-V, and 1200-V MPT IGBT technologies. Static and dynamic values are provided at T_J = 150 °C and with V_{DC} = 2/3 · V_{CES}. As reference, 650-V and 1200-V state-of-the-art 4th-generation IGBTs are indicated as well.

Source: Christian R. Müller, et al. "New 950-V IGBT and diode technology integrated in a low-inductive ANPC topology for solar applications", PCIM Euro, 2019

Compared with 1200V T4 chip, 950V chips

- Has ~50% chip area at same I_{cnom}
- S7: E_{off} reduced~60%, similar V_{CE}
- L7: V_{CE} reduced ~35%, E_{off} increased ~70%

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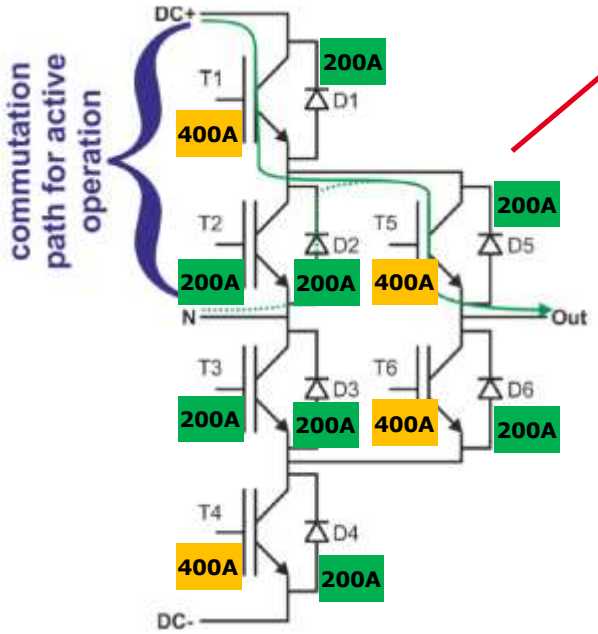
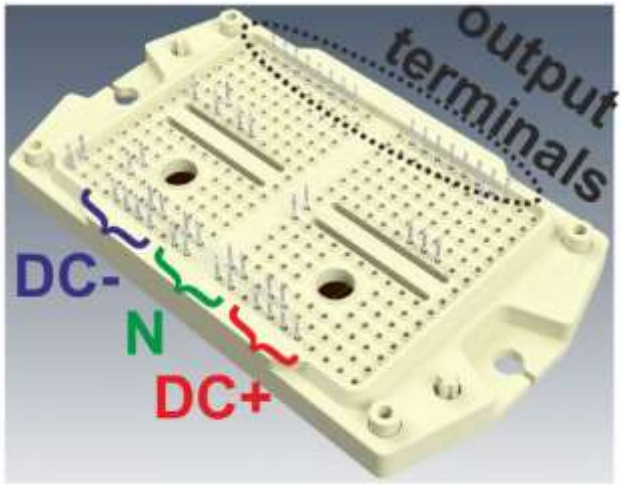
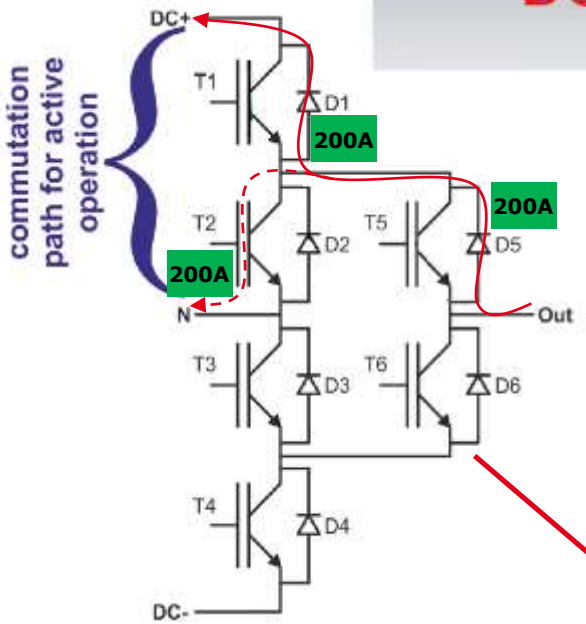
State of the art power modules for solar application - String



Designed for solar





Not designed for ESS

Fig. 4. S7 and L7 are implemented in the subsystems T1 to T4 and T5 to T6, respectively. Whereas T2 and T3 provide an I_{nom} of 200 A, all other IGBTs have an I_{nom} value of 400 A. With respect to the diode, two main scenarios are analyzed: in the first one, 200 A RAPID diodes are integrated in all subsystems. In the second

Source: Christian R. Müller, et al. "New 950-V IGBT and diode technology integrated in a low-inductive ANPC topology for solar applications", PCIM Euro, 2019

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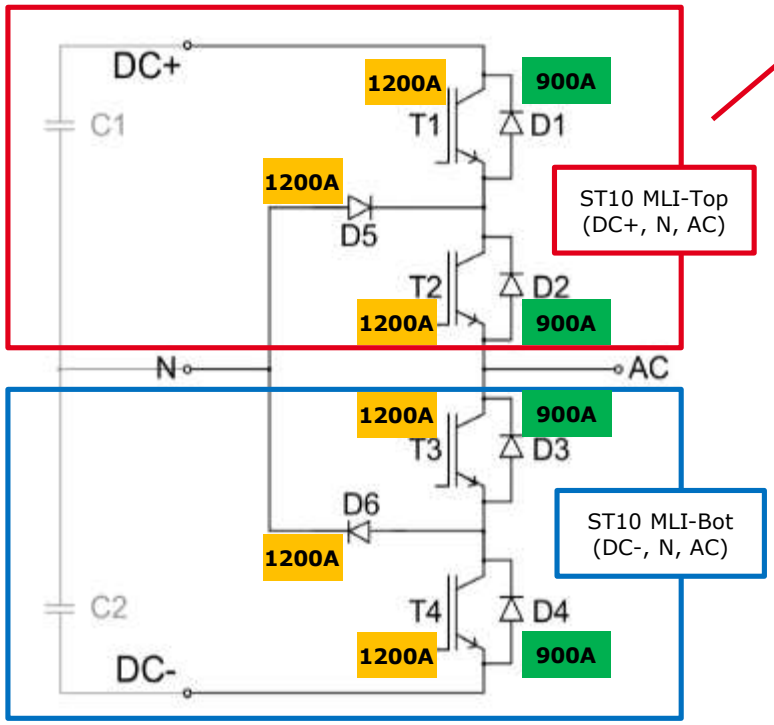
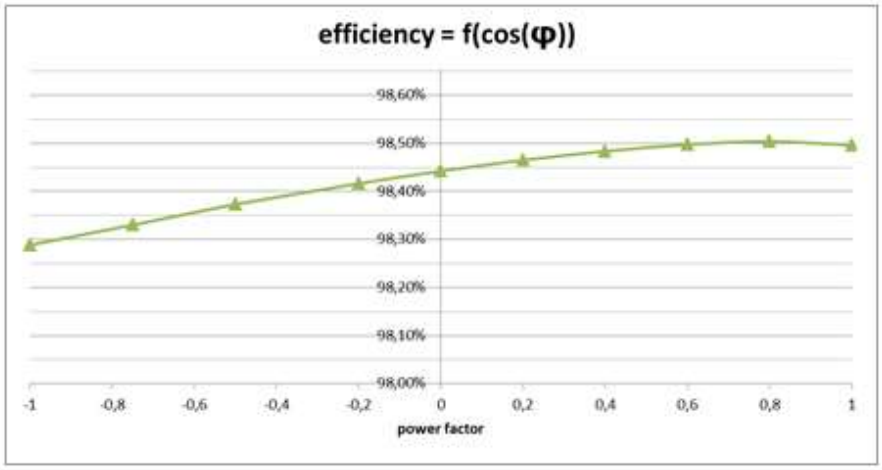
State of the art power modules for solar application - Central



Designed for solar



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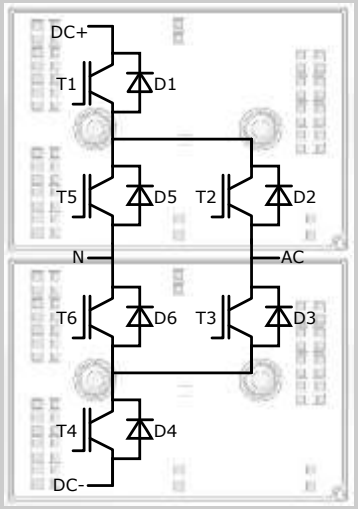
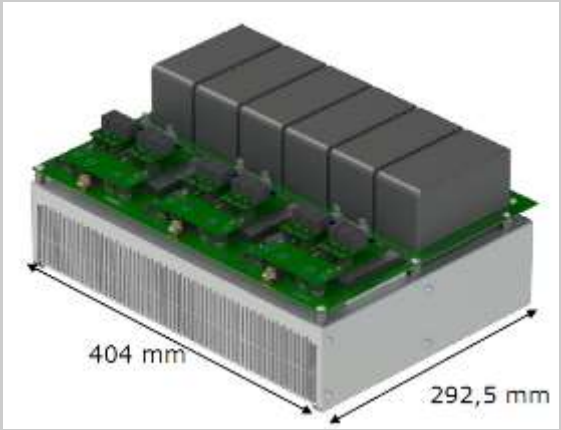
3-level Central Converter Design

3-level Commutation Difficulties

Summery

Split ANPC solution with optimized chips for Solar and ESS





Chip configuration for Solar

Switch	Chip	Technology	I_{nom}	Voltage	Amount	I_{total}
T1/T4	IGC86T95U12RS	S7	200A	950V	3	**600A**
T5/T6	IGC86T95U12RS	S7	200A	950V	1	**200A**
D1/D4	IDC29D95Q8	EC7	100A	950V	3	**300A**
D5/D6	IDC29D95Q8	EC7	100A	950V	3	**300A**
T2/T3	IGC86T95U12RV	L7	200A	950V	2	**400A**
D2/D3	SKCD53C120I4F	CAL4F	100A	1200V	3	**300A**

Chip configuration for ESS

Switch	Chip	Technology	I_{nom}	Voltage	Amount	I_{total}
T1/T4	IGC86T95U12RS	S7	200A	950V	3	**600A**
T5/T6	IGC86T95U12RS	S7	200A	950V	3	**600A**
D1/D4	IDC29D95Q8	EC7	100A	950V	6	**600A**
D5/D6	IDC29D95Q8	EC7	100A	950V	4	**400A**
T2/T3	IGC86T95U12RV	L7	200A	950V	2	**400A**
D2/D3	SKCD53C120I4F	CAL4F	100A	1200V	5	**500A**

Split ANPC for Solar

Operation condition:

Vdc = 1350V

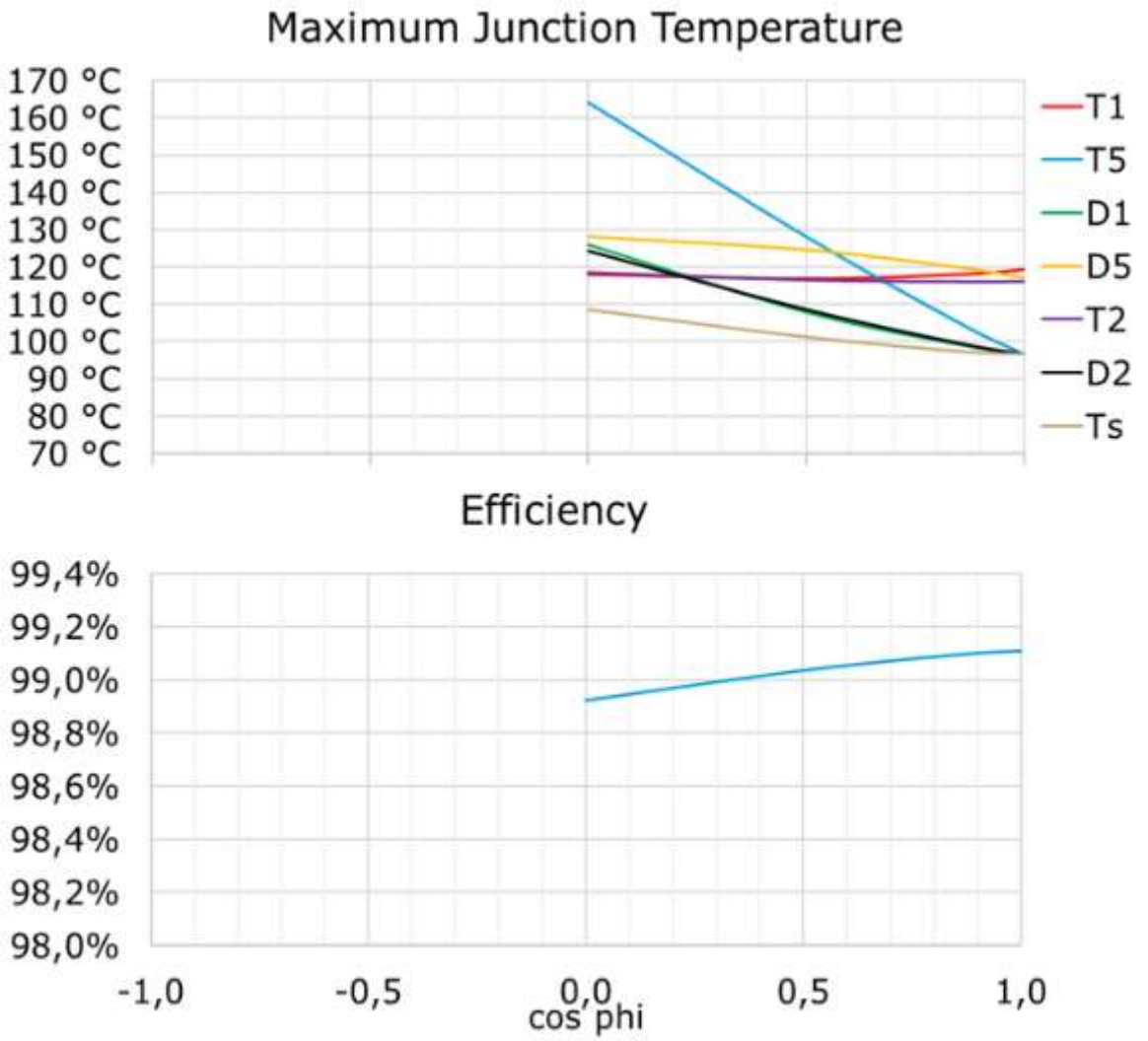
Vout = 800V

Pout = 277kW

fsw = 16kHz

Ta = 40°C

Cooling: air



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Split ANPC for ESS

Operation condition:

Vdc = 1400V

Vout = 690V

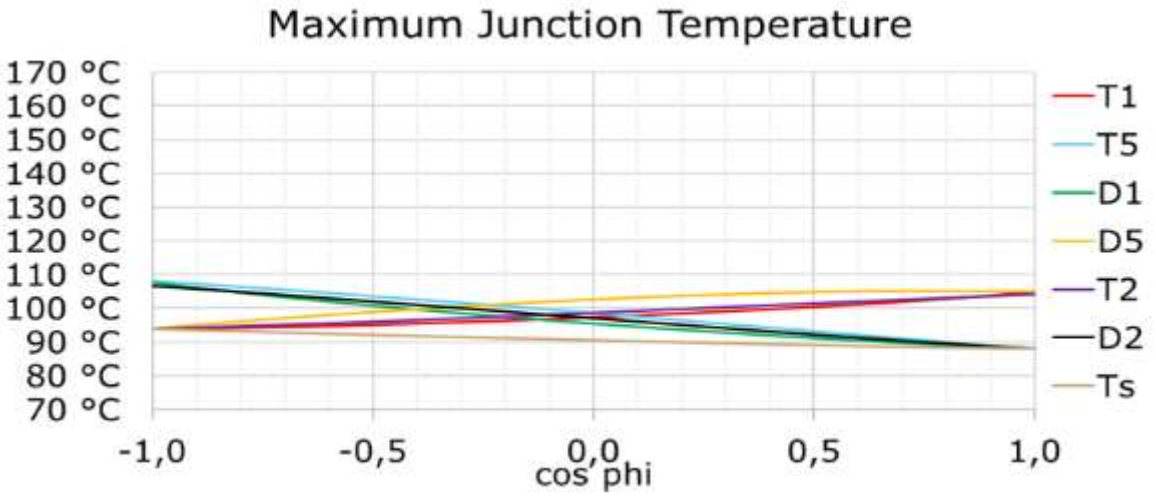
Pout = 225kW

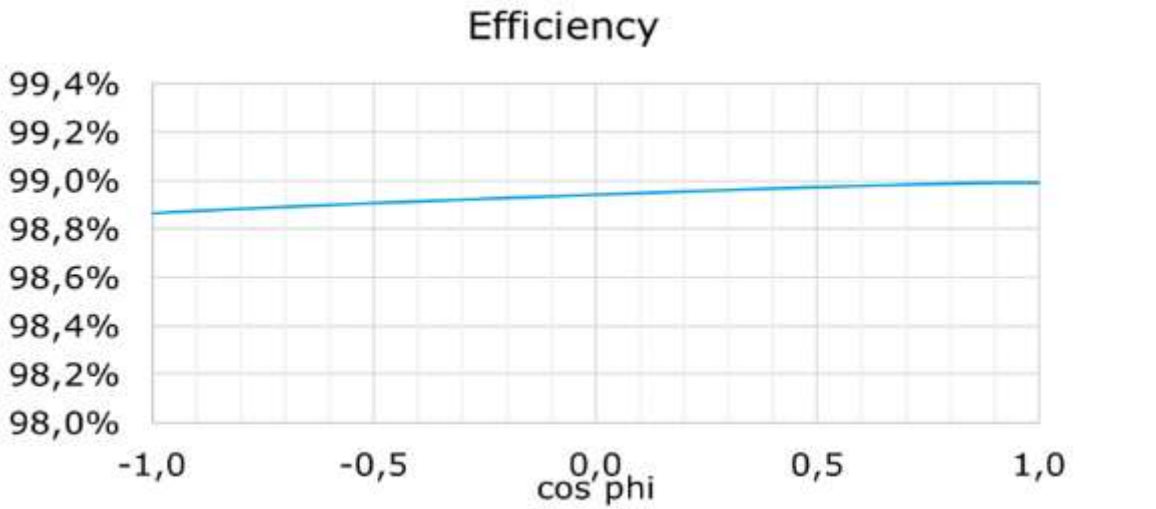
fsw = 16kHz

Ta = 40°C

Cooling: air

Output power should reach to 300kW





SKiiP 38ANPC10S7V10

3 level ANPC split (TOP)

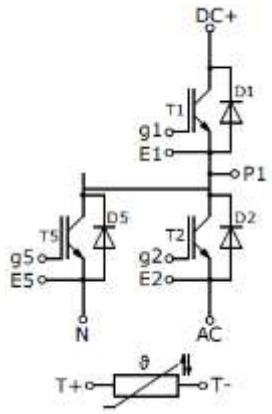
Target Data

Features

- 7th generation IGBTs in 950V
- Highly reliable spring contacts for electrical connections
- NTC T-Sensor

Typical Applications

- Energy storage



MiniSKiiP® 3

Si-Version	T1/T4/T5/T6	D1/D4	D5/D6	T2/T3	D2/D3
I_{nom} [A]	600	600	400	400	500
Performance	**S7**	**EC7**	**EC7**	**L7**	**CAL4F**
Vce/Vf @150°C	2.2 V	2.15 V	2.15 V	1.35 V	2.15 V
E_{on}* [mJ]	30.5	-	-	Not considered	Not considered
E_{off}* [mJ]	24.4	13.2	8.8	Not considered	Not considered

* at T_j=150°C, I=I_{nom}, V_c=600V

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SKiiP 38ANPC10S7V20

3 level ANPC split (BOT)

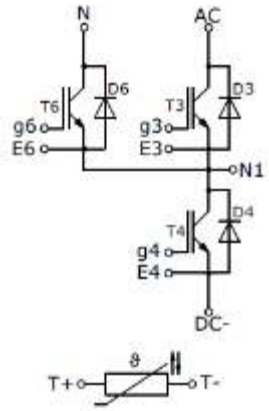
Target Data

Features

- 7th generation IGBTs in 950V
- Highly reliable spring contacts for electrical connections
- NTC T-Sensor

Typical Applications

- Energy storage



MiniSKiiP® 3

Si-Version	T1/T4/T5/T6	D1/D4	D5/D6	T2/T3	D2/D3
I_{nom} [A]	600	600	400	400	500
Performance	**S7**	**EC7**	**EC7**	**L7**	**CAL4F**
Vce/Vf @150°C	2.2 V	2.15 V	2.15 V	1.35 V	2.15 V
E_{on}* [mJ]	30.5	-	-	Not considered	Not considered
E_{off}* [mJ]	24.4	13.2	8.8	Not considered	Not considered

* at T_j=150°C, I=I_{nom}, V_c=600V

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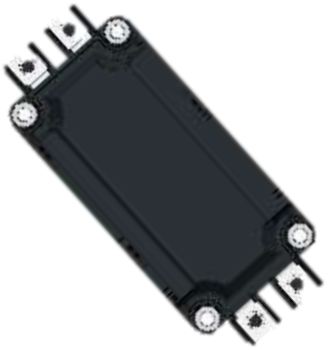
3-level Commutation Difficulties

Summery

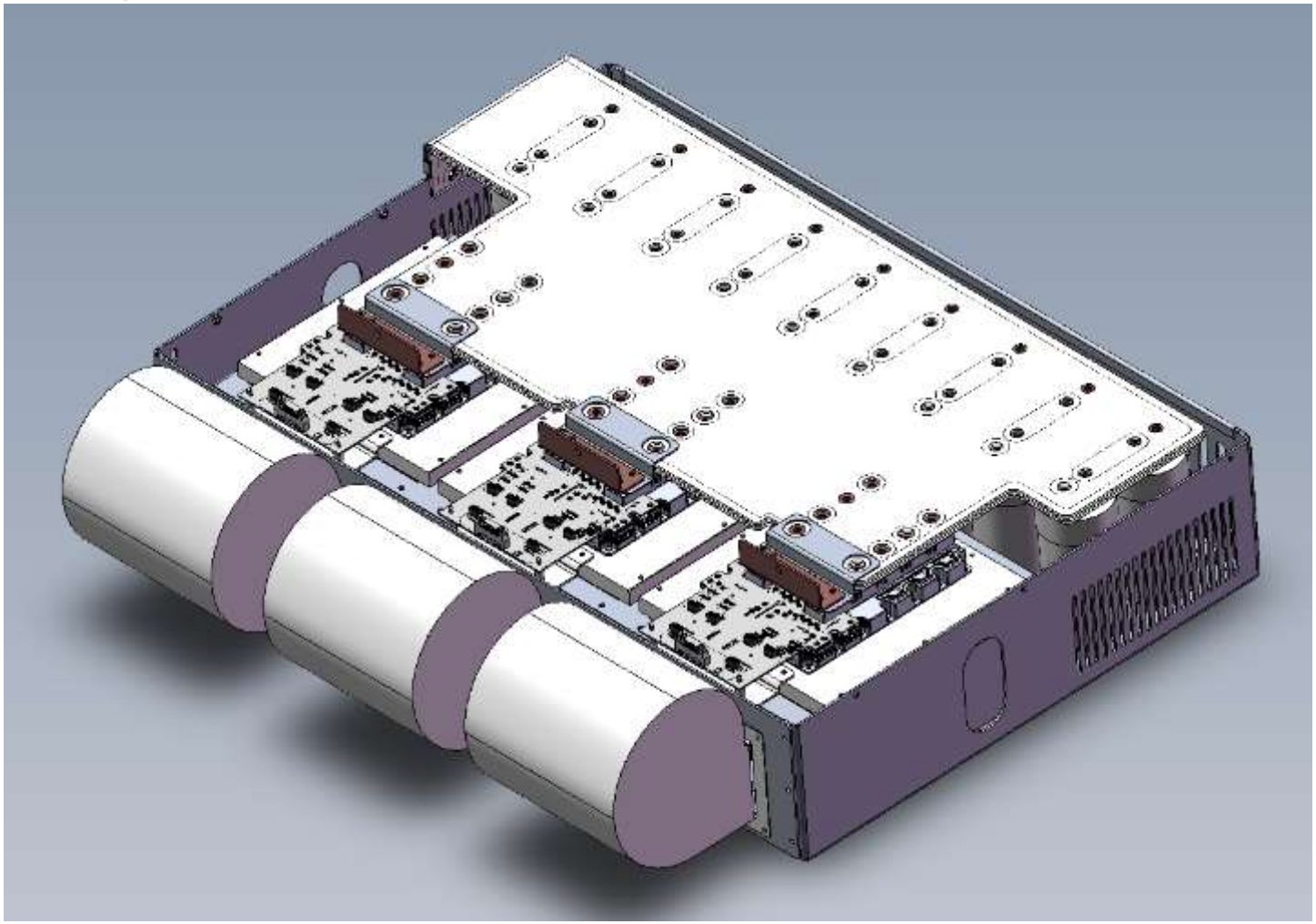
Focus Solar Central Inverter

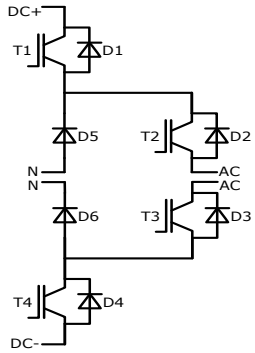
Which power module is matching with your requirements?

- cost of power module
- system cost
- current density

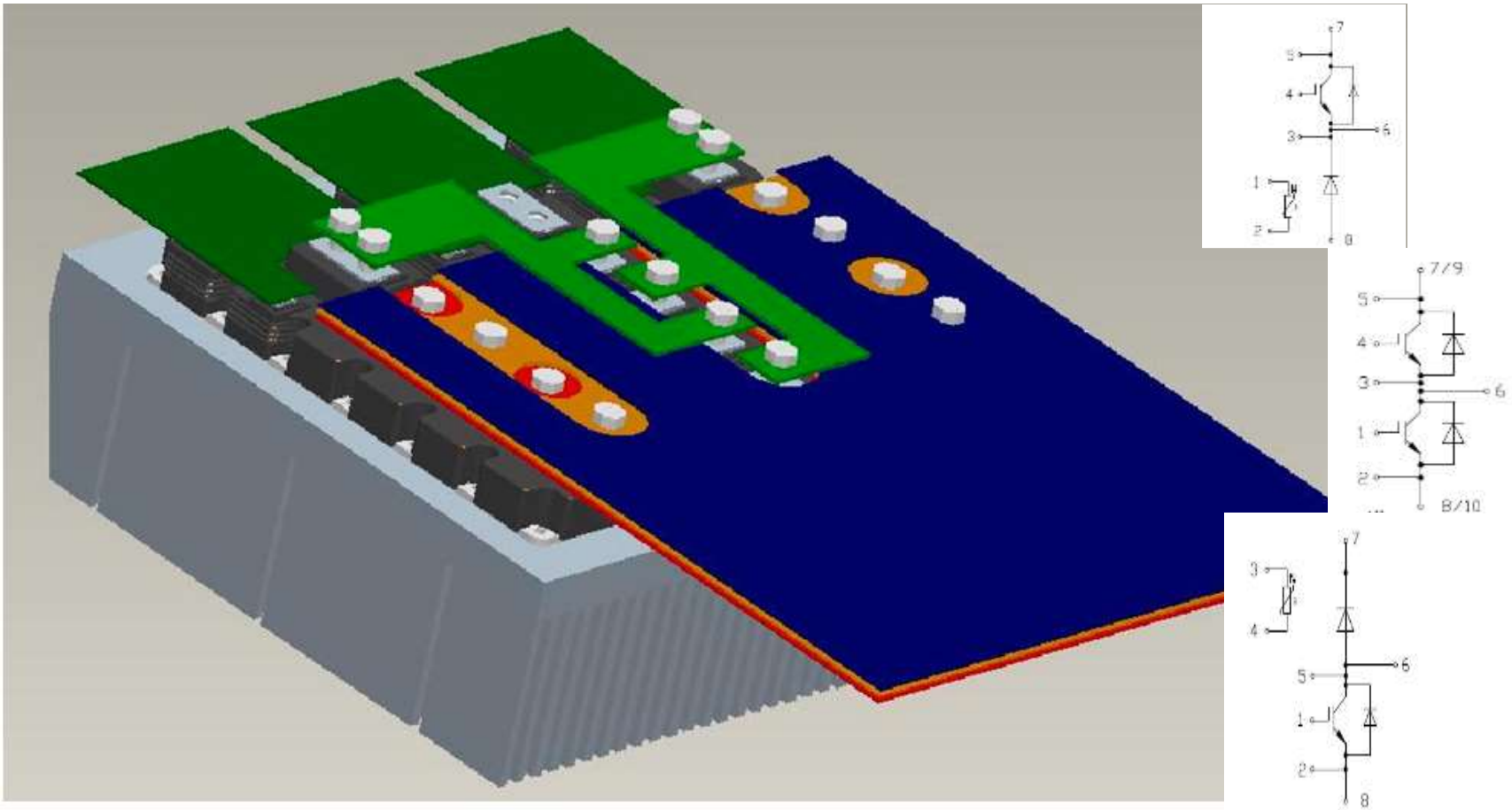


3 Phase Solar Inverter Design 500-750kW





3-level-design with Primepack – Infineon Application proposal



3 level topology with PrimePACK™ halfbridge and chopper FD and DF

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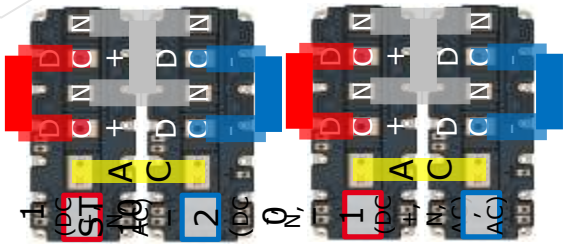
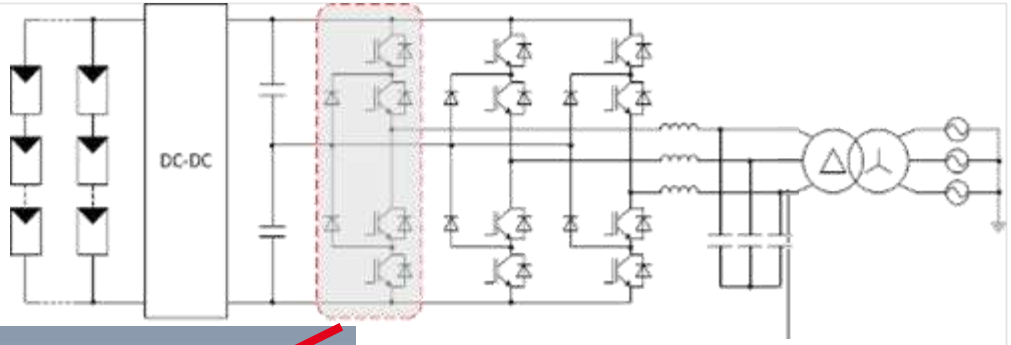
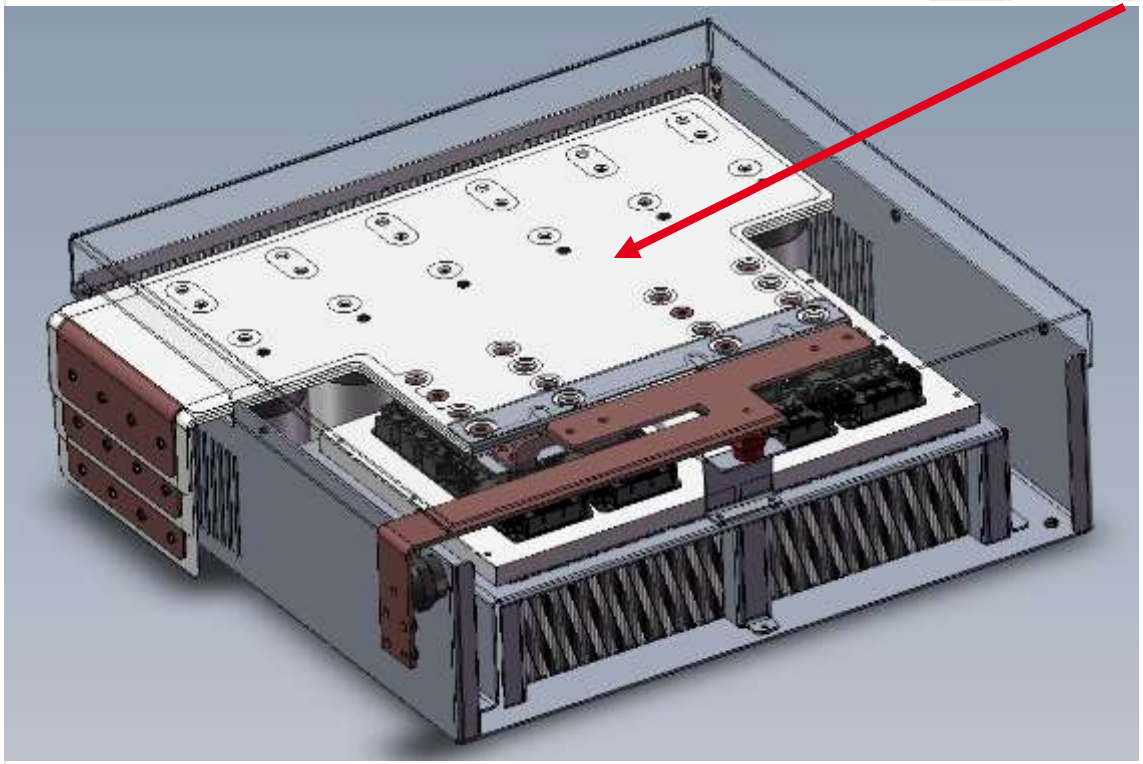
1 - 1.5MW Solar Converter – one phase (2 pairs in parallel)







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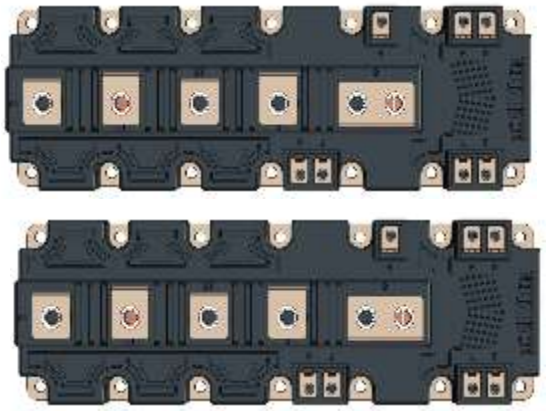
Goal:

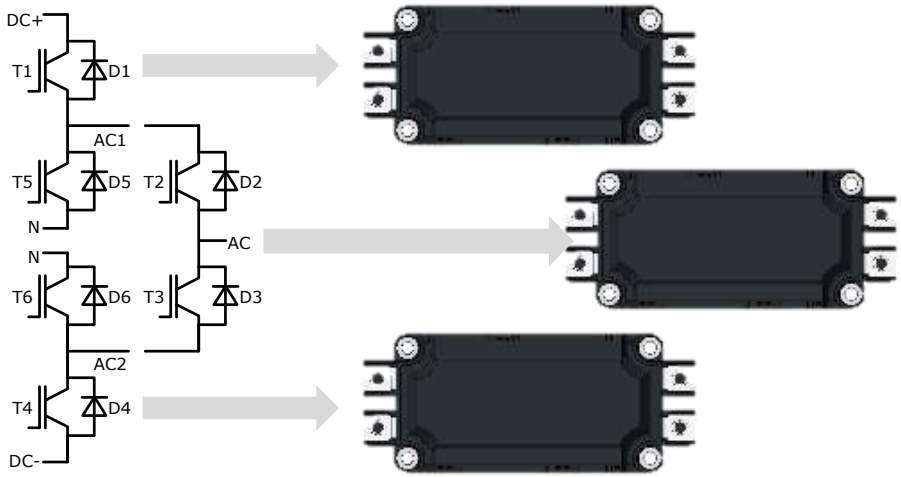
Comparison among Semitrans 10 split NPC vs. SEMiX3p based NPC with respect to:

- Material
- Manufacturing
- Performance

SEMITRANS split NPC



SEMiX3p



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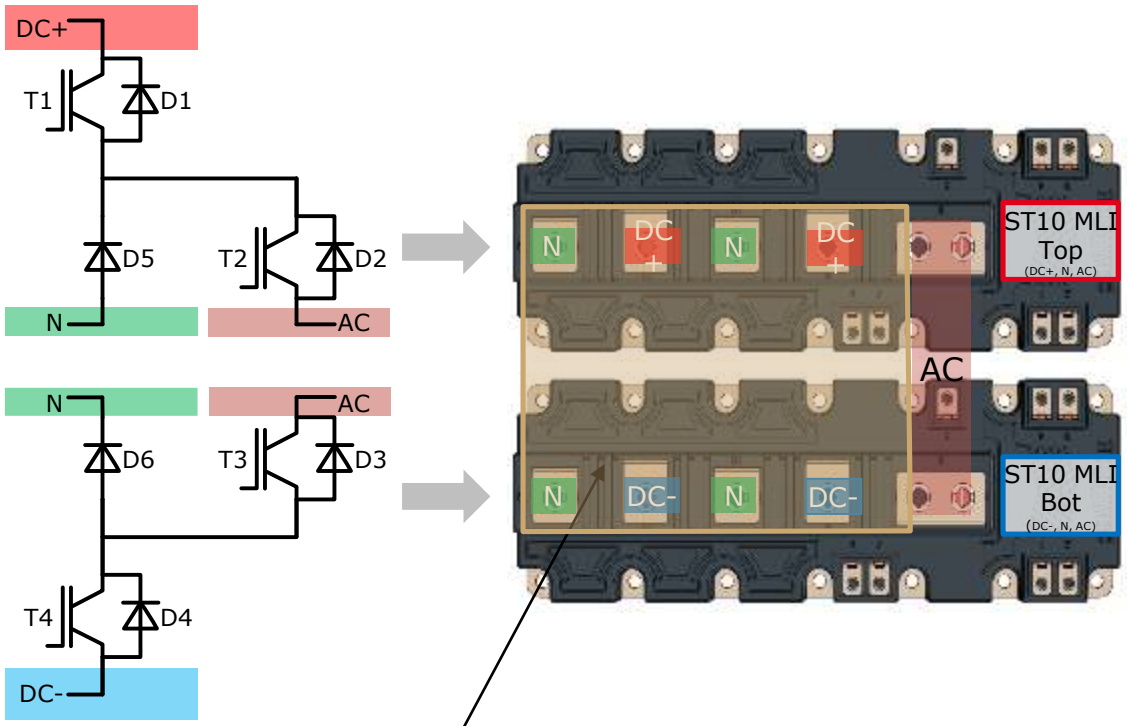
ST10 split NPC

DC+ / N / DC- overlapping → **reduced DC Link inductance**

Partly overlapping with AC terminal to **further reduce stray inductance down to 64nH** between two modules

The colors of the terminals relate to the colors of the drawing



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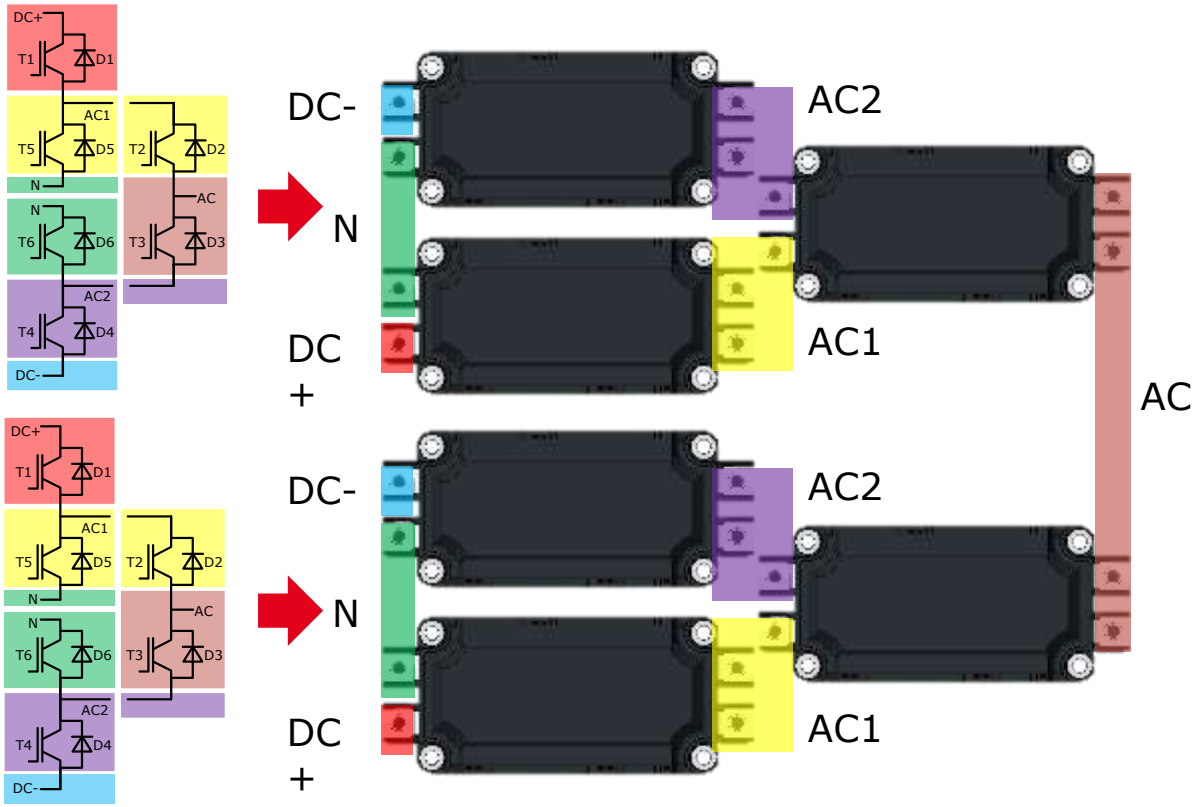
SEMiX3p as NPC

No overlapping of all 5 DC layers possible → **increased DC Link inductance**

Propably **AC-choke** necessary for current balance

No Common driver board possible

The colors of the terminals relate to the colors of the drawing



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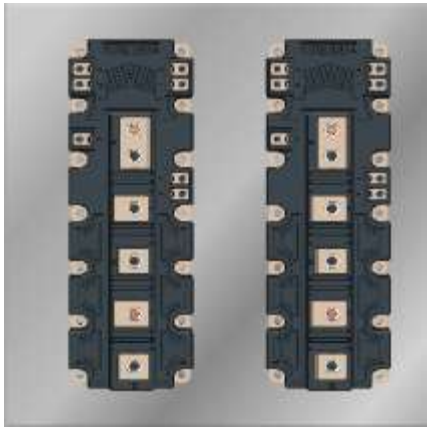
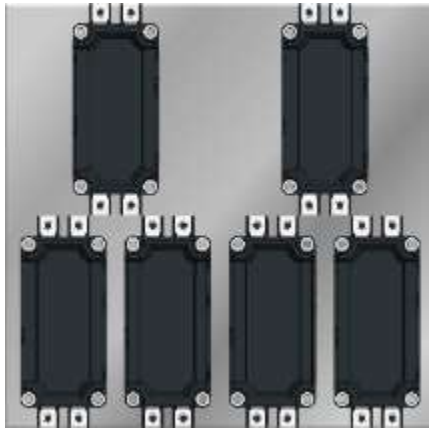
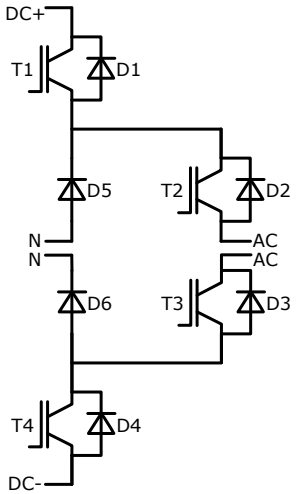
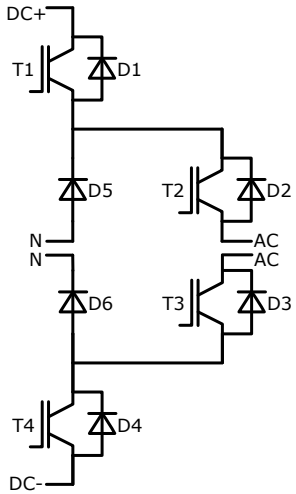
Equivalent setup



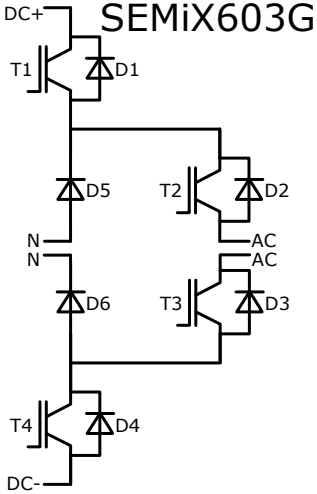


SKM1200MLI12E4
SKM1400MLI12M7





SEMiX603GB12E4



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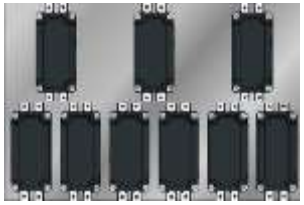
Scaleability

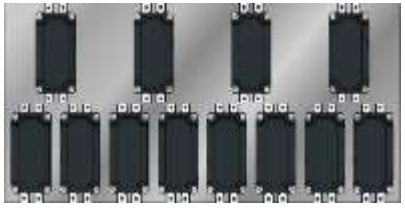
SKM1200MLI12E4
SKM1400MLI12M7

SEMiX603GB12E4

equivalent



equivalent



Heat sink

Assumption:

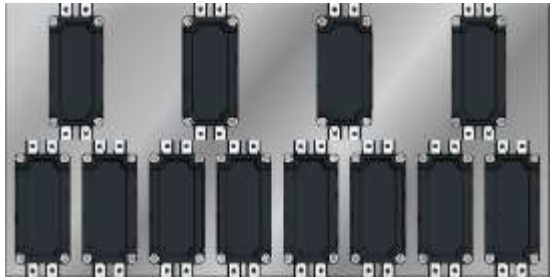
Both module variants use the same heat sink

Standard heat sink from Mersen

Serrated fin with Alpha fin option

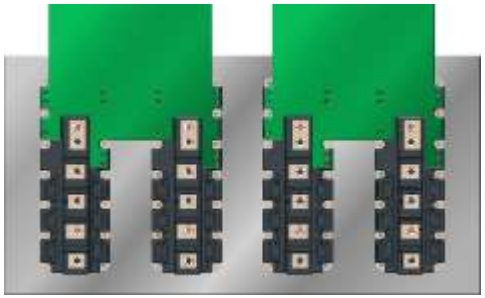
Heat sink	Value
Length [mm]	600.00
Width [mm]	300.00
Fin pitch [mm]	5.49
Fin thickness [mm]	1.25
Fin length [mm]	89.00
Root thickness [mm]	12.7
Weight [kg]	13.9

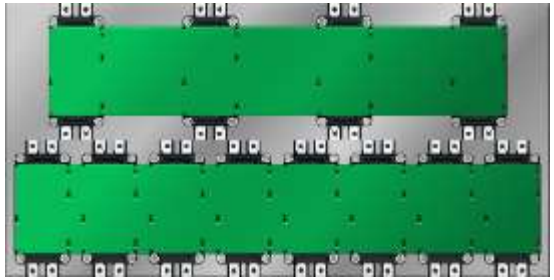
Screws – Module to heat sink



Semitrans10 split NPC		Screws		SEMiX3p
Amount	cost		Amount	cost
56x M5		Module to heat sink	48x M5	

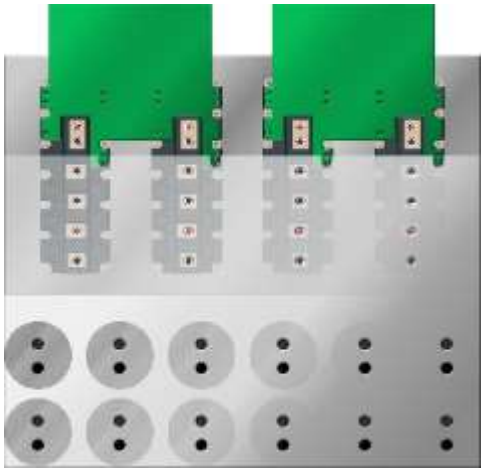
Screws – Driver

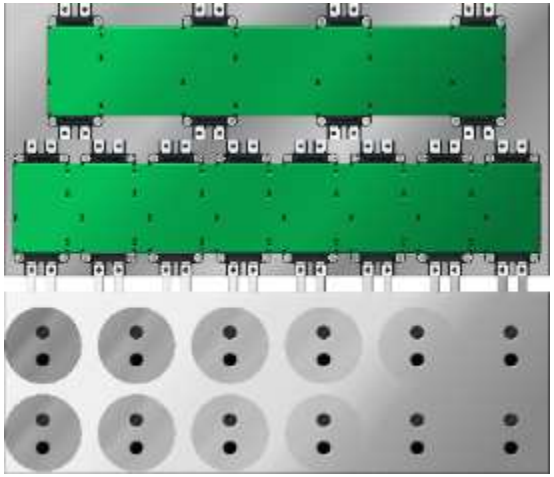




Semitrans10 split NPC		Screws		SEMiX3p
Amount	cost		Amount	cost
56x M5		Module to heat sink	48x M5	
28x M4		Driver	48x M2.5	

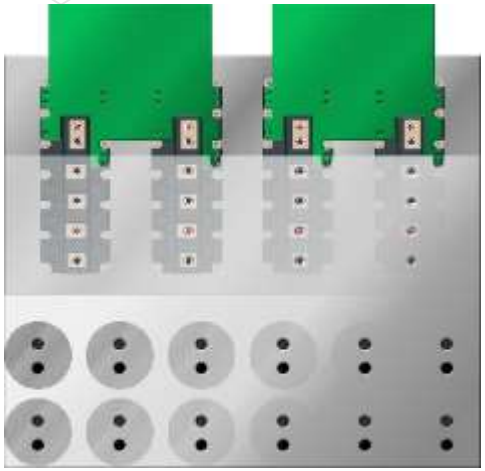
Screws – DC Link to module

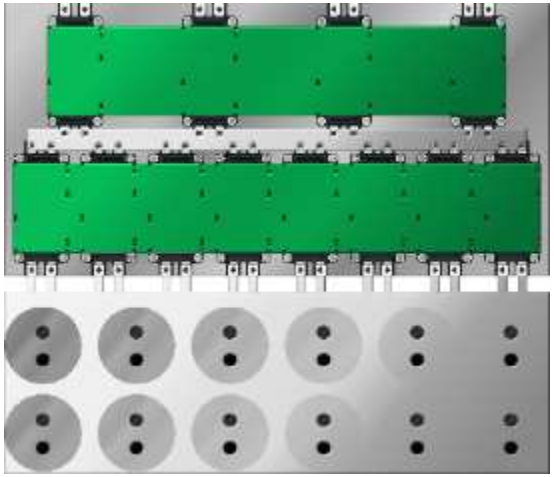




Semitrans10 split NPC		Screws		SEMiX3p
Amount	cost		Amount	cost
56x M5		Module to heat sink	48x M5	
28x M4		Driver	48x M2.5	
16x M8		DC Link to module	16x M6	

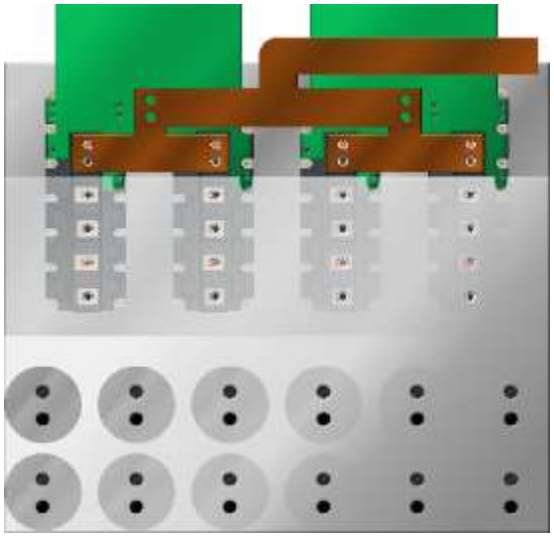
Screws – Output stage

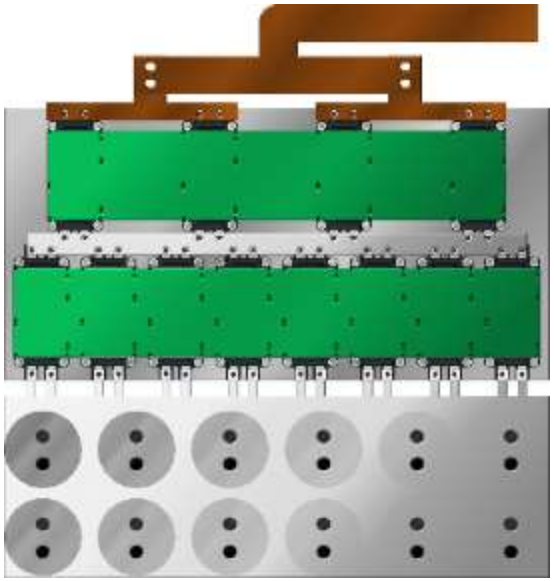




Semitrans10 split NPC		Screws		SEMiX3p
Amount	cost		Amount	cost
56x M5		Module to heat sink	48x M5	
28x M4		Driver	48x M2.5	
16x M8		DC Link to module	16x M6	
-		Output stage	24x M6	

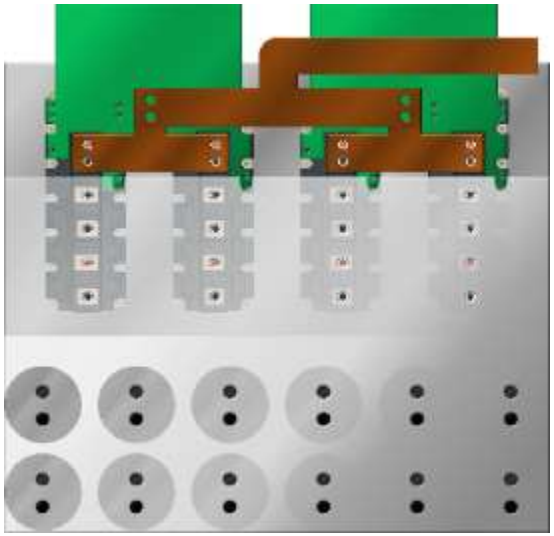
Screws – AC bar to module

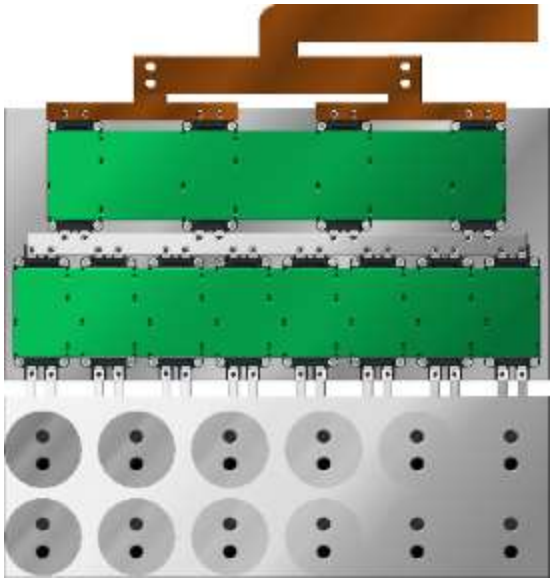




Semitrans10 split NPC		Screws		SEMiX3p
Amount	cost		Amount	cost
56x M5		Module to heat sink	48x M5	
28x M4		Driver	48x M2.5	
16x M8		DC Link to module	16x M6	
-		Output stage	24x M6	
8x M8		AC bar to module	8x M6	

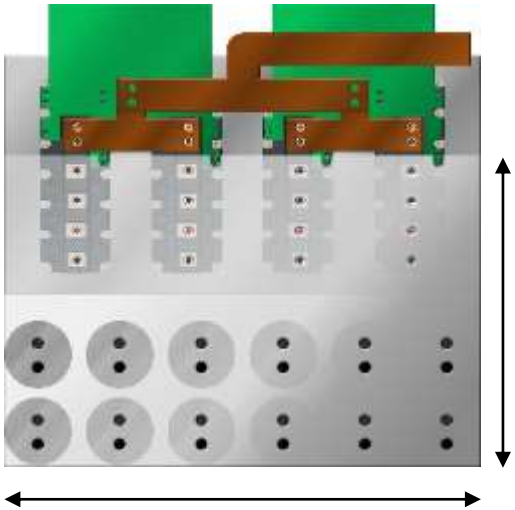
Screws - Summary

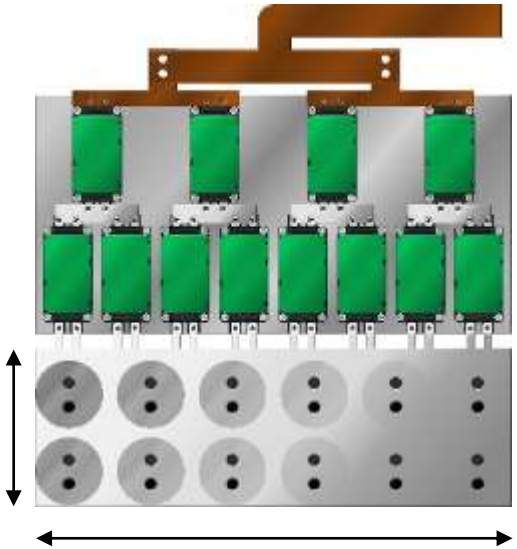




Semitrans10 split NPC		Screws		SEMiX3p
Amount	cost		Amount	cost
56x M5		Module to heat sink	48x M5	
28x M4		Driver	48x M2.5	
16x M8		DC Link to module	16x M6	
-		Output stage	24x M6	
8x M8		AC bar to module	8x M6	
106		**Total screws**	**144**	

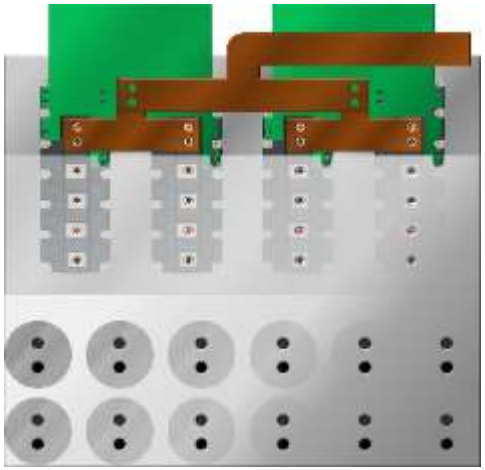
DC Link

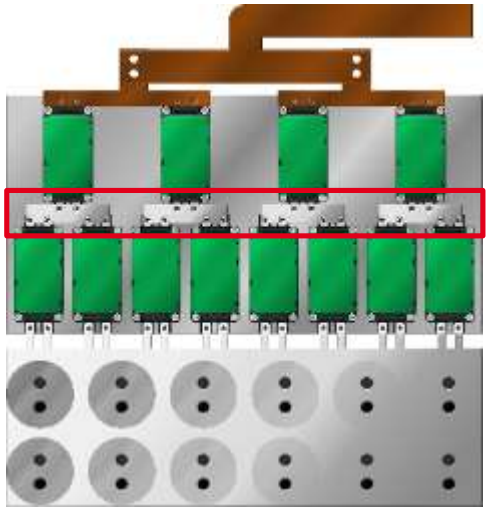




Semitrans10 split NPC		SEMiX3p
DC+ / N / DC-	DC Link Layers	DC+ / N / DC-
600	Width [mm]	600
392	Length [mm]	200
tbd	cost	tbd

output stage





Semitrans10 split NPC		SEMiX3p
-	Output stage Layers	Out 1 / Out 2
0	cost	tbd

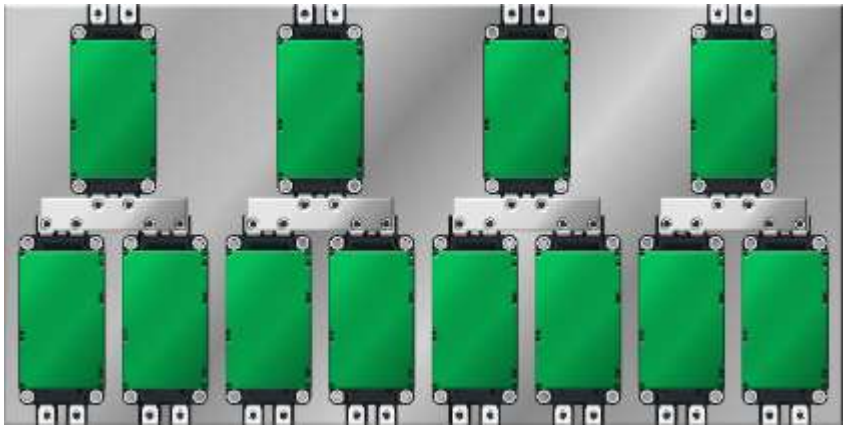
Driver

Driver board solution for SEMiX3p could be single drivers with adapters in between connected by control cable

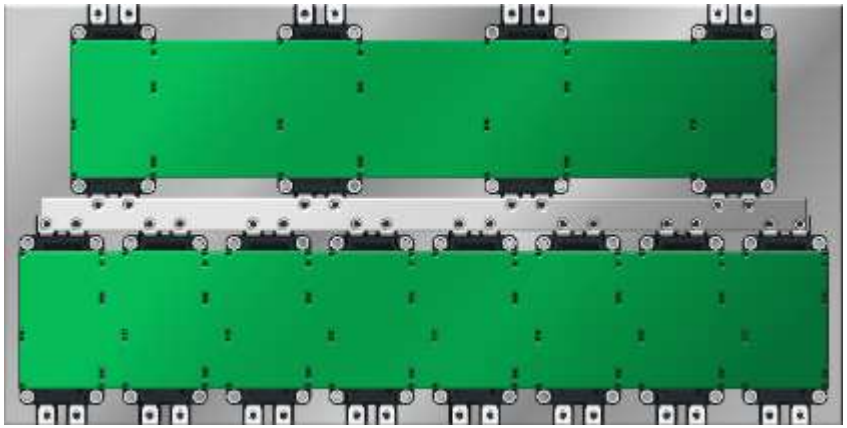
Up to

2 different driver PCB for input and output stage

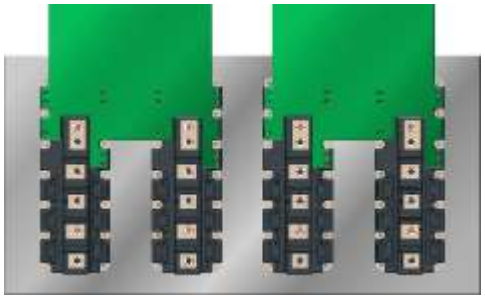
Single drivers

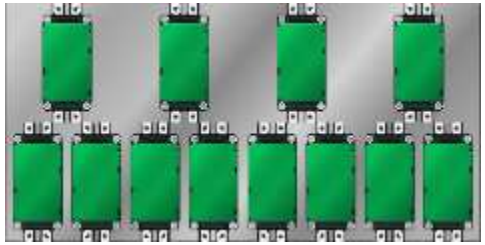


2 different driver boards



Driver PCB





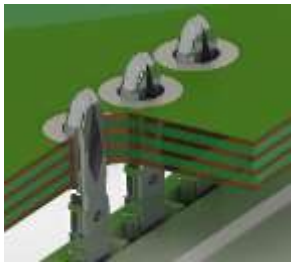
Semitrans10 split NPC	PCB	SEMiX3p
tbd	cost	tbd

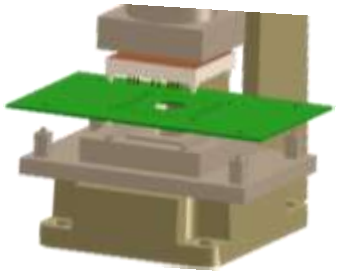
Soldering / pressfit pins for SEMiX3p

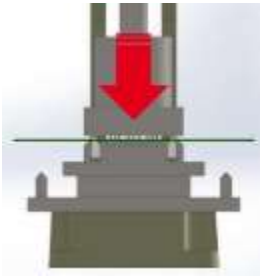
The pressfit SEMiX3p modules can either be connected to the PCB by pressfit or soldering.

In both cases different equipment is required with **additional costs**

pressfit

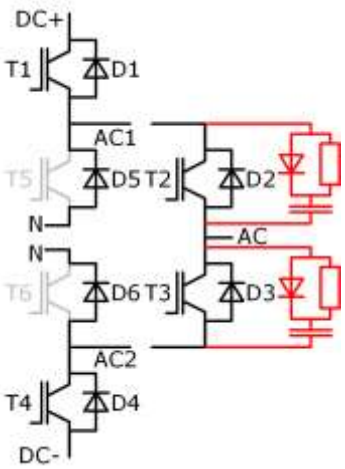


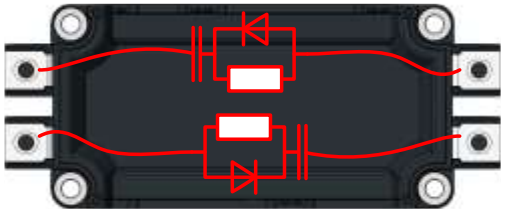




pressfit

SEMiX3p – RCD snubber





AC

Option	Mechanical construction	Remarks
1		Pressfit pins not connected
2		Probably insufficient contact between PCB and Output stage / AC bar connector
3		ok

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SEMiX3p – RCD snubber

Operating area 1 and 3:
T2/T3 switching
→ RCD snubber active

Operating area 1 and 3:
T2/T3 no switching
→ RCD snubber not active

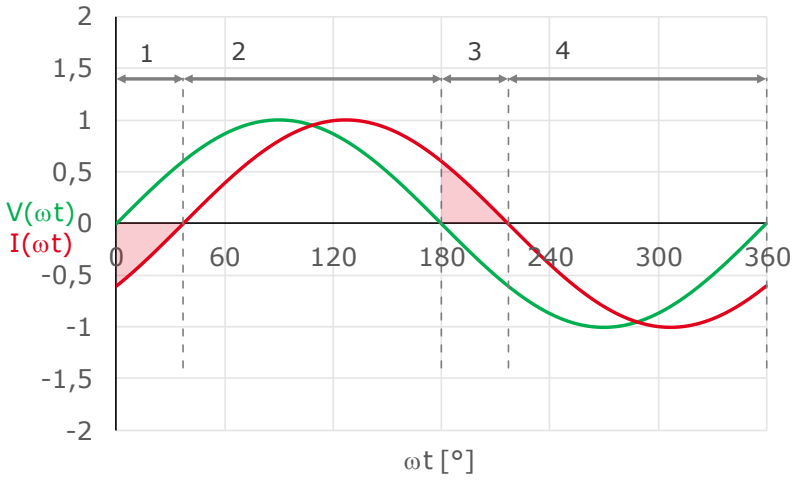
Power losses in RCD snubber depend on application condition

In solar application RCD snubber less active than in wind application

→ Additional losses in snubber for SEMiX3p solution

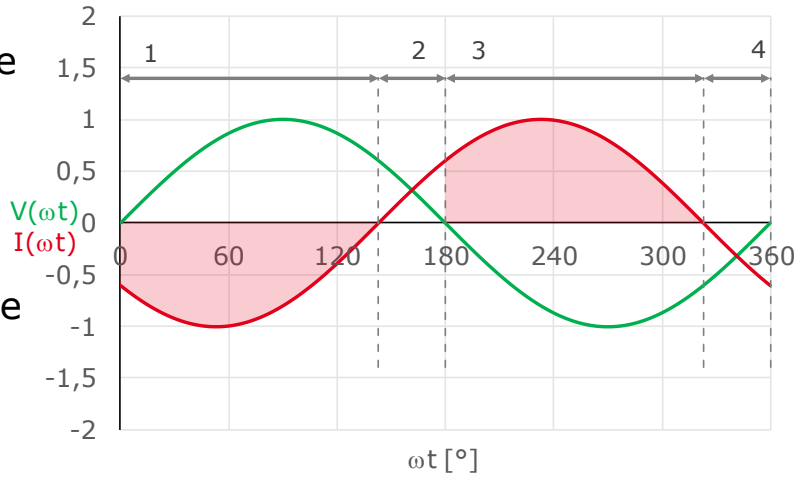
Solar:
Cosphi=0.8
→ RCD snubber active for 40°

60% of I_{max}
→ lower overvoltage



Wind: generator side
Cosphi=-0.8
→ RCD snubber active for 140°

100% of I_{max}
→ higher overvoltage



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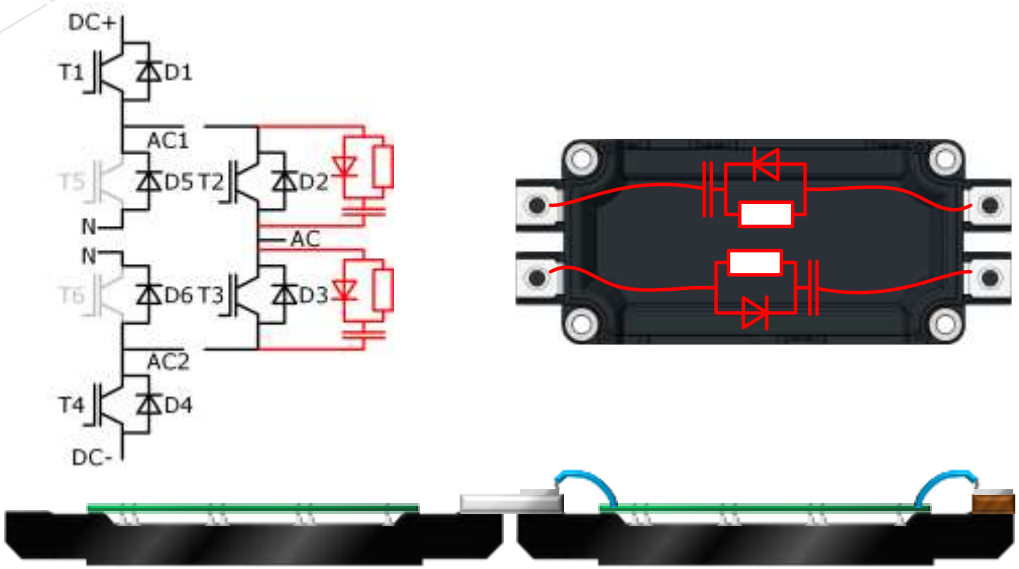
SEMiX3p – Summary RCD snubber



RCD snubber	Cost	Per module	Total costs
Diode 		2	tbd
Resistor 		2	tbd
Capacitor 		2	tbd
heat sink for diode 		2	tbd
Cable 		4	tbd
			tbd

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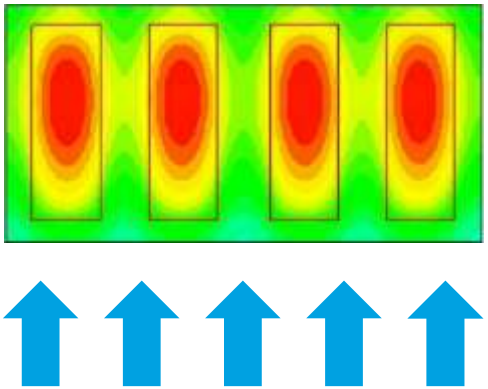
Solar application

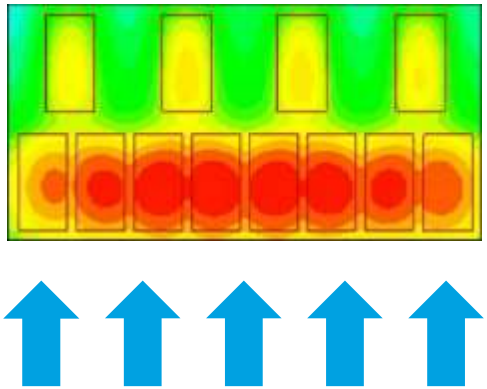
4x SEMITRANS10 split NPC



1000m³/h

Solar application:
V_{DC} = 1200 V
V_{LL} = 550 V
I_{out} = 1365 A
P_{out} = 1.3 MW
f_{out} = 50 Hz
f_{sw} = 4 kHz
cosphi=1
Cooling: air

12x SEMiX3p



1000m³/h

Semitrans10 split NPC		SEMiX3p
SKM1400MLI12M7		SEMiX603GB12E4
1000	Air volume [m³/h]	1000
0,0118 (100%)	R_{thj-s} [K/W] for all modules	0,0108 (92%)
120	T_{jmax} [°C]	122
4807 (100%)	Total Power losses Inverter [W]	5332 (111%)
-	Power losses RCD snubber [W]	tdb
4807 (100%)	**Total Power losses [W]**	**5332 + tdb**

Summary costs

SEMITRANS10 split NPC	Material costs	SEMiX3p
tbd	Module costs	tbd
tbd	Screw costs	tbd
0	RCD network	tbd
tbd	DC Link	tbd
0	Output stage	tbd
	Driver	

SEMITRANS10 split NPC	Labour costs	SEMiX3p
tbd	Mounting	tbd
0	Soldering / pressfit	tbd

Packaging Technology in different Application

Introduction of solar & ESS

2-level & 3-level features

3-level for ESS & Solar (ANPC)

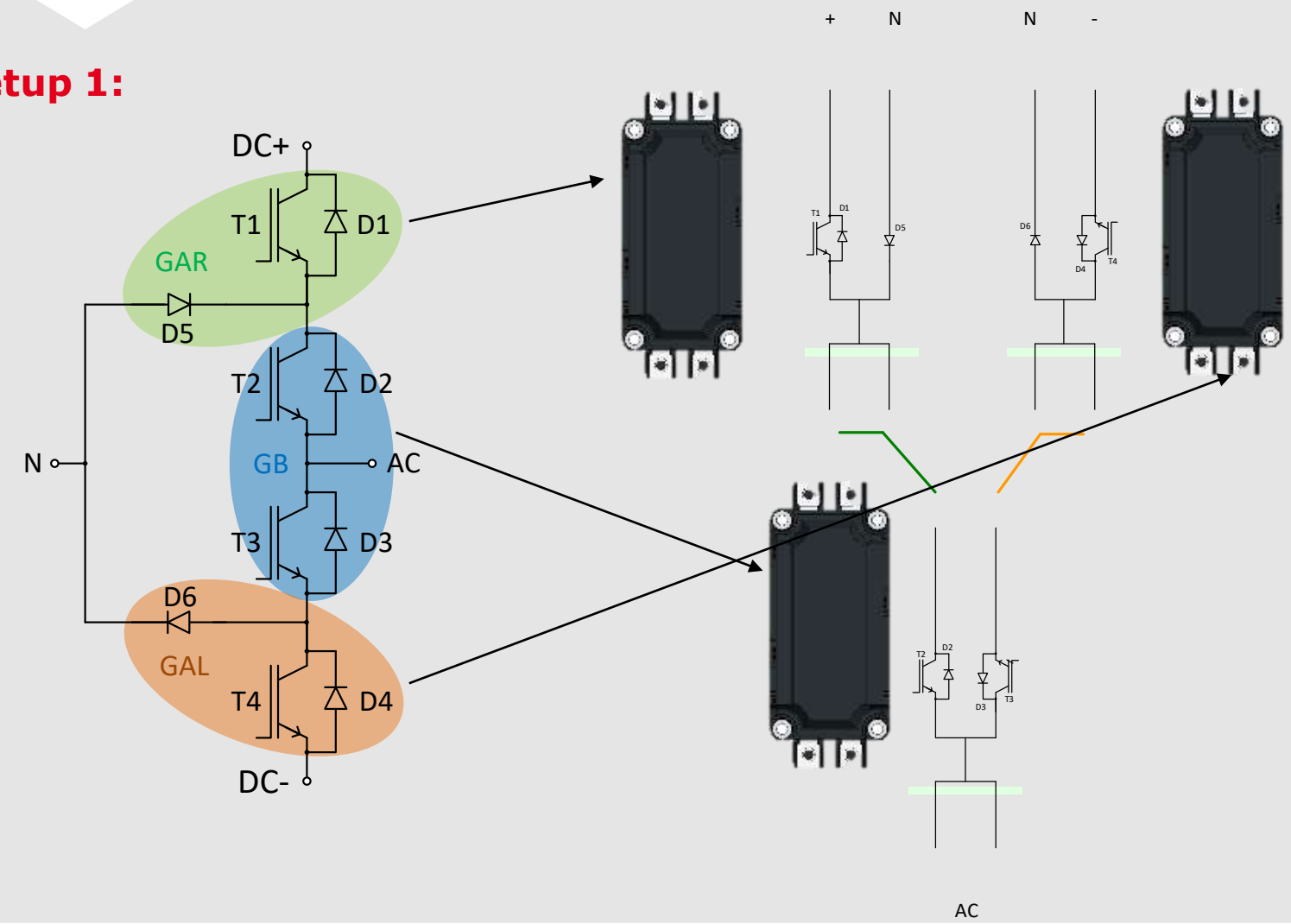
3-level Central Converter Design

3-level Commutation Difficulties

Summery

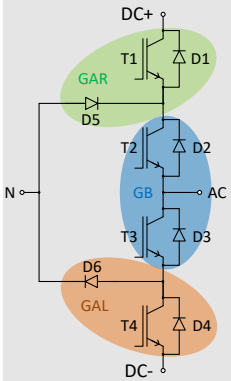
GAR(GB), GB and GAL(GB): Setup 1

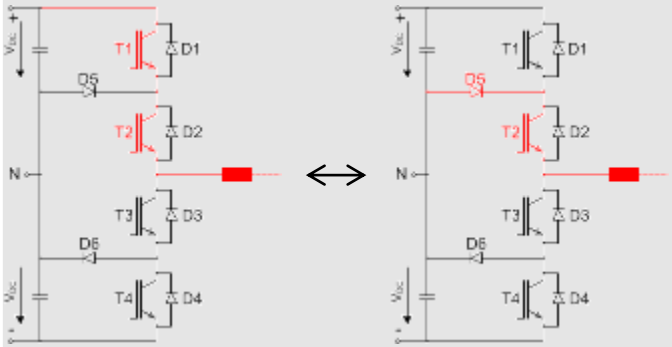
Setup 1:

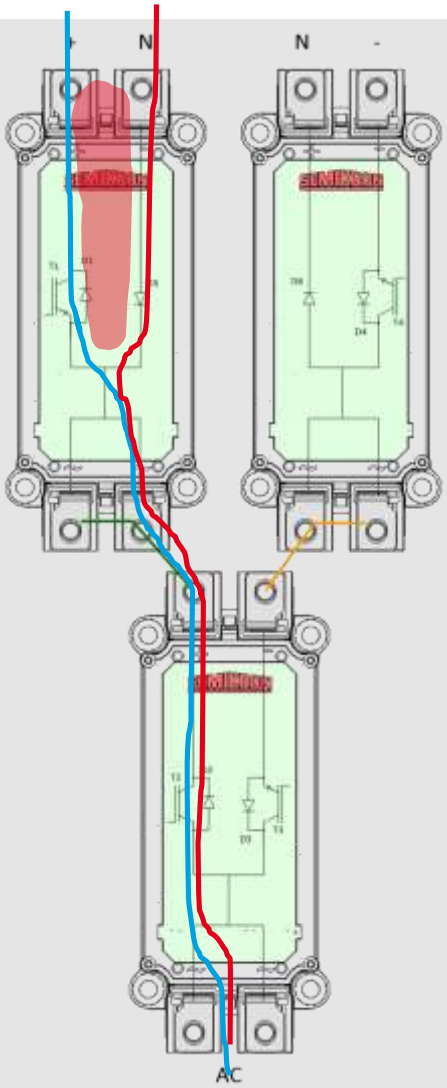


GAR, GB and GAL: Setup 1

Setup 1: current paths and short commutation loop T1/T2 ⇔ D5/T2

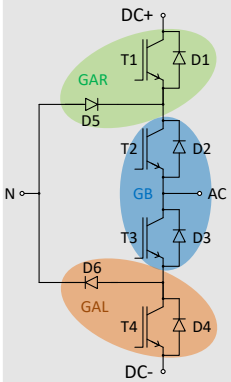


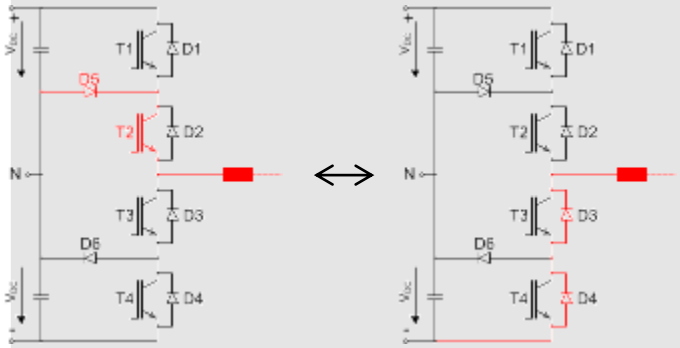


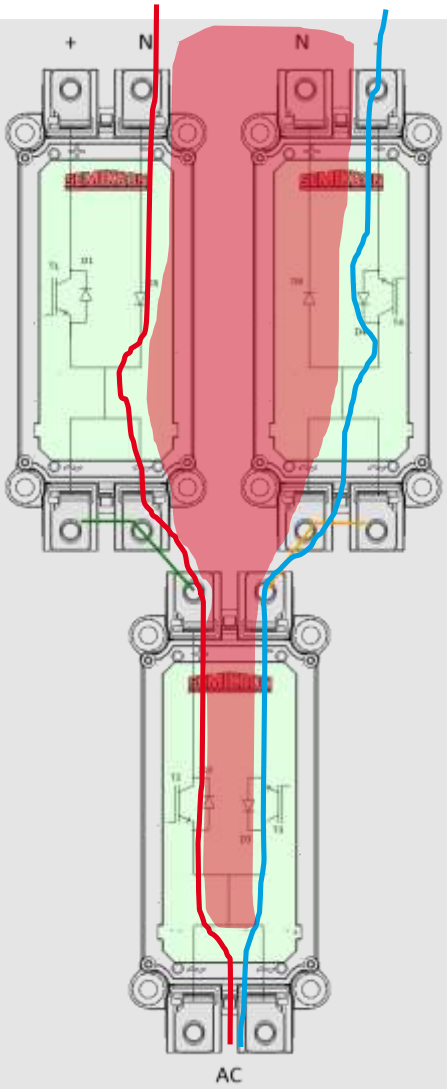


GAR, GB and GAL: Setup 1

Setup 1: current paths and long commutation loop D5/T2 ⇔ D3/D4



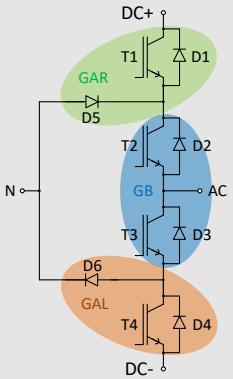


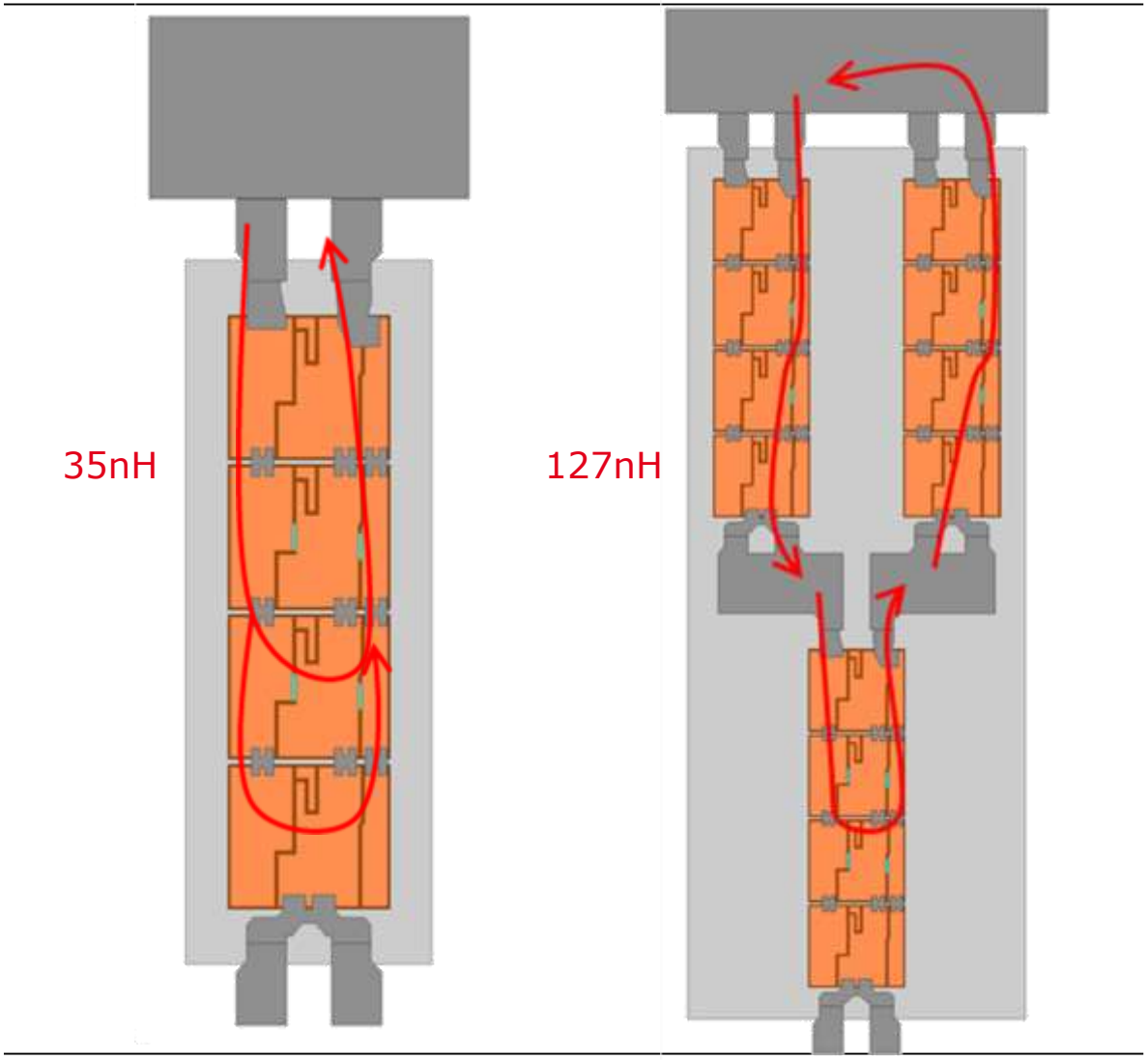


GAR, GB and GAL: Setup 1

Setup 1 stray inductances:

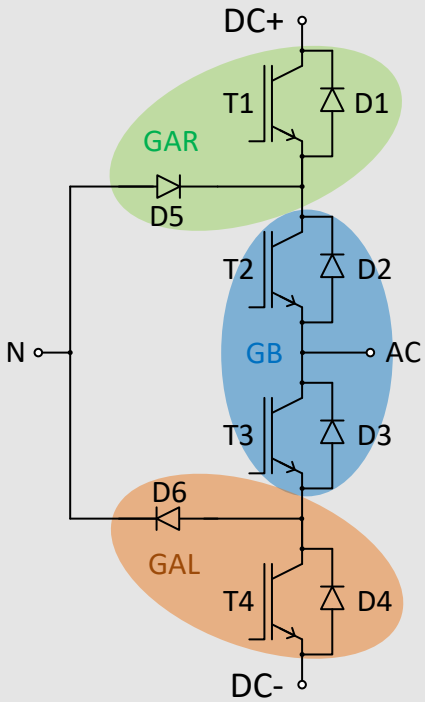
- **Short commutation path inside one module: 35nH**
- **Long commutation path across module boundaries: 127nH**

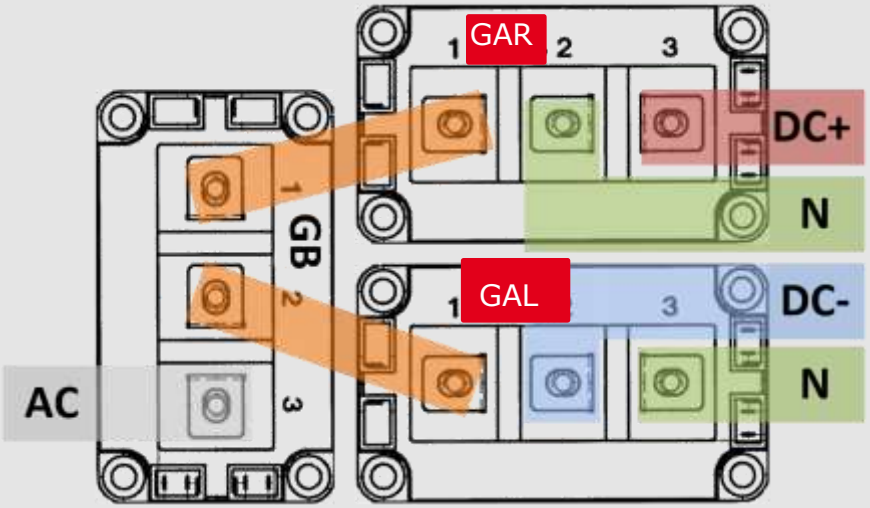




3L NPC Setup with SEMITRANS

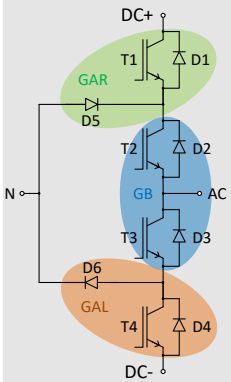
Setup A:GAR

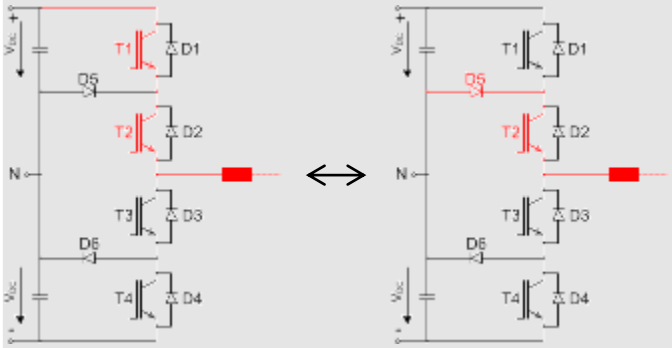


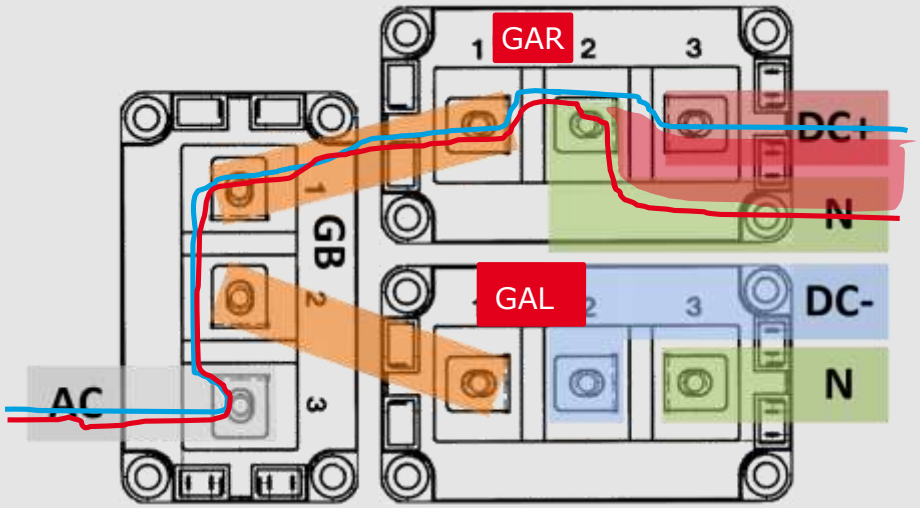


SEMITRANS GAR, GB and GAL: Setup A

Setup A: current paths and short commutation loop T1/T2 ⇔ D5/T2

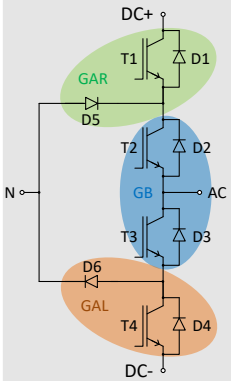


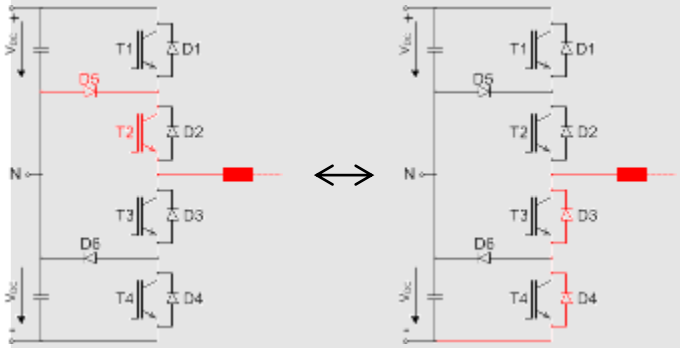


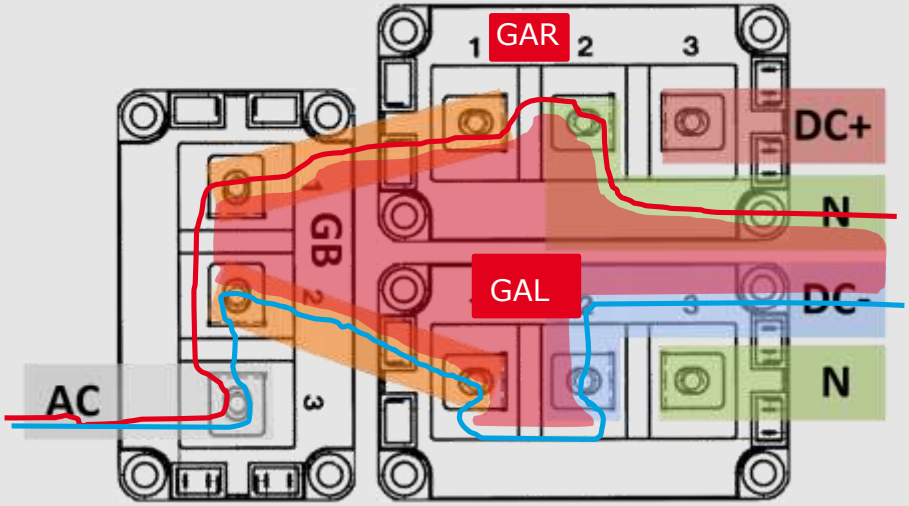


SEMITRANS GAR, GB and GAL: Setup A

Setup A: current paths and long commutation loop D5/T2 ⇔ D3/D4



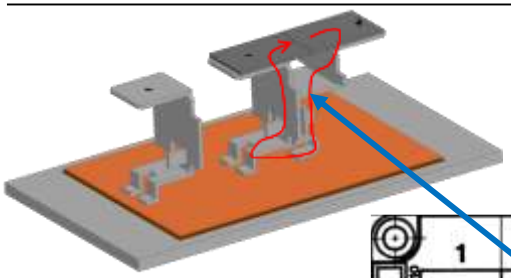




SEMITRANS Stray Inductance – Competitor Stray Inductance

Setup A stray inductances:

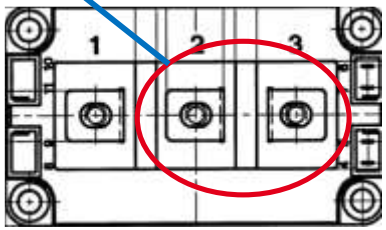
- **Short commutation path: 12nH**
- **Long commutation path across module boundaries: 99nH**
- **Reduction to 60nH with laminated busbar possible**

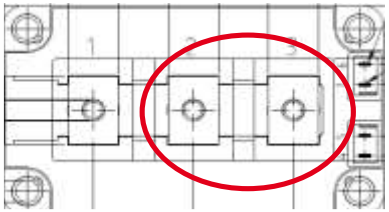


12nH

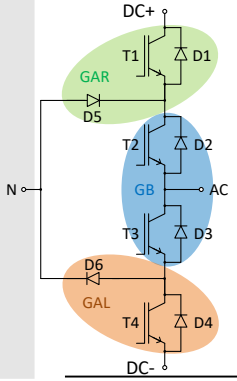
Competitor above 15nH

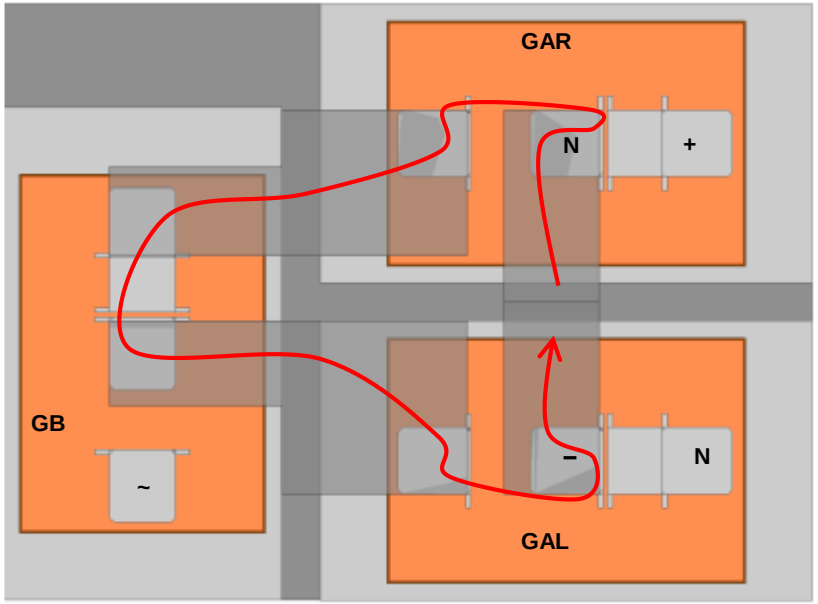
Check terminal design





99nH





Packaging Technology in different Application

Introduction of solar & ESS

2-level & 3-level features

3-level for ESS & Solar (ANPC)

3-level Central Converter Design

3-level Commutation Difficulties

Summery

Summery Solar & ESS

- Cost pressure is getting higher and higher
- Reliability is a MUST
- Solar & ESS Converter as one unit, power factor -1
- Power factor -1 means – selection of the right diode inside the power module to improve efficiency
- Air cooled System are common
- Consider environment and creepage distance

Contact

Norbert Pluschke

Technical Director Greater China

Semikron Hong Kong Co. Ltd.

E-mail: Norbert.Pluschke@Semikron.com

MP:+85298201603

Semikron Electronics (Zhuhai) Co., Ltd.

Unit 1, Ground Floor, 2#, Unit 2,4,5,7, Ground Floor, 5#, Manufacturing Center, No.1 Software Road, Tangjia, Zhuhai, Guangdong 519080, PR China, Tel: 86-756-3396707