pcim ASIA Hybrid Platform

Active neutral point clamped (ANPC) three-level converter for high power applications with optimized PWM Strategy

Wang Heng, Infineon China

speaker

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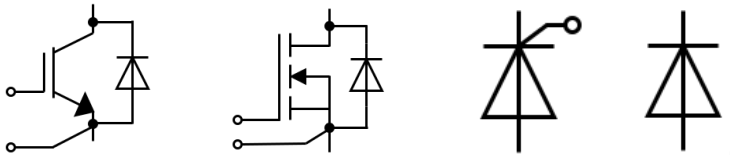
- **Company:** Infineon China
- **Position:** Field Application Engineer

- **Background**
  - Bachelor / Master degree in Electrical Engineering
  - R&D engineer in ENPC
  - FAE in Infineon since 2010



Contents

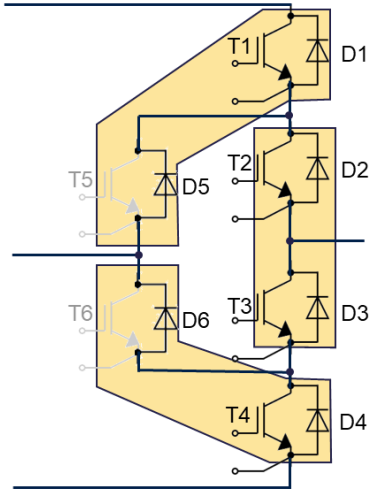
Background

- More and more applications prefer to 3L solution from kinds of purposes (e.g. higher power rating, higher efficiency, higher voltage usage…)

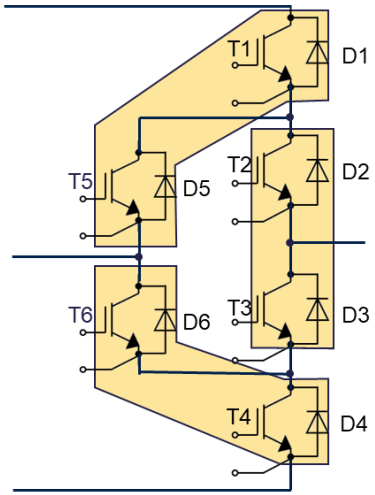
- **Example:**
  - Offshore wind turbine
  - 1500V solar inverter

- **IGBT module:**
  - The most common IGBT power module is in half-bridge topology for 2L application

How to compose a 3L solution by standard half-bridge IGBT module?

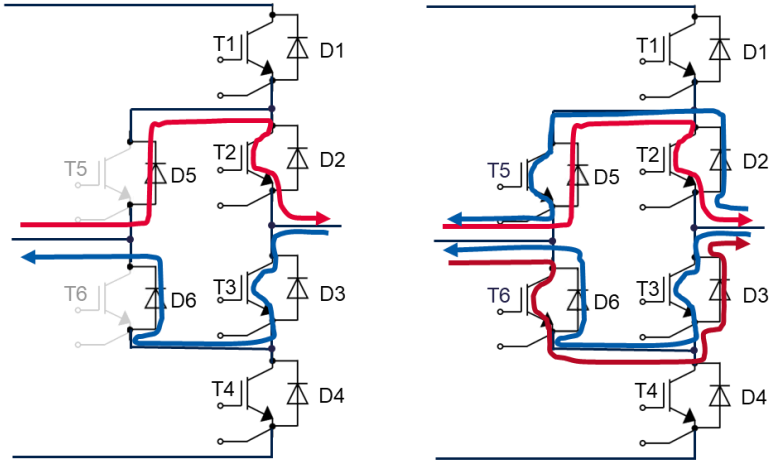


a) NPC1



b) ANPC

› Current conduction paths



a) NPC1 b) ANPC

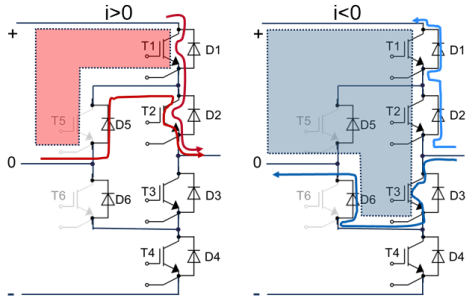
	NPC1	ANPC
+1	T1→T2→ →D2→D1	T1→T2→ →D2→D1
0	D5→T2→ →T3→D6	T6→D3→ (New) D5→T2→ →T3→D6 →D2→T5 (New)
-1	→T3→T4 D4→D3→	→T3→T4 D4→D3→

Optimization targets from ANPC

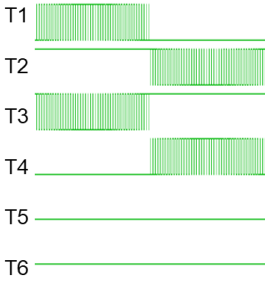
- **More safe**
  - to improve the commutation loop and obtain the minimum parasitic inductance. This helps to reduce the voltage spike or suppress switch oscillation from diode or IGBT.
- **More efficiency**
  - to reduce the losses of the whole system in order to increase efficiency.
- **More power output**
  - to balance the power loss among switches to increase output power.

2. The PWM method of ANPC
The method for improving the commutation loop

1. Classical NPC1-PWM0

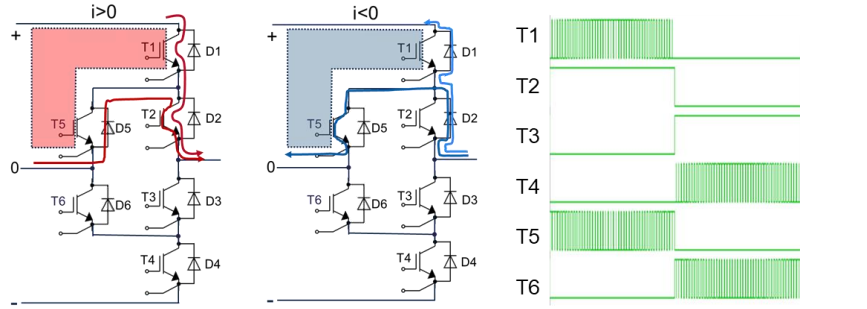


a) Commutation loop of NPC1



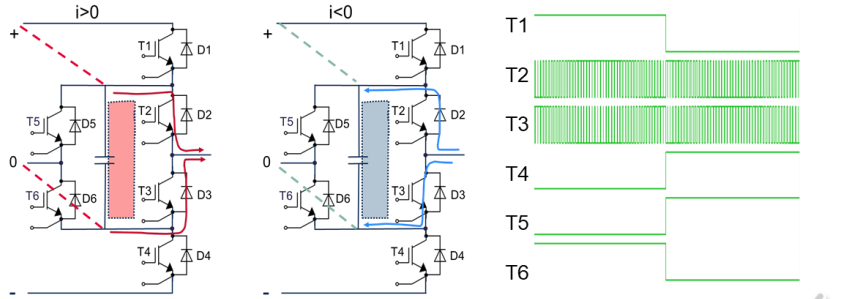
b) PWM of NPC1

ANPC-PWM1



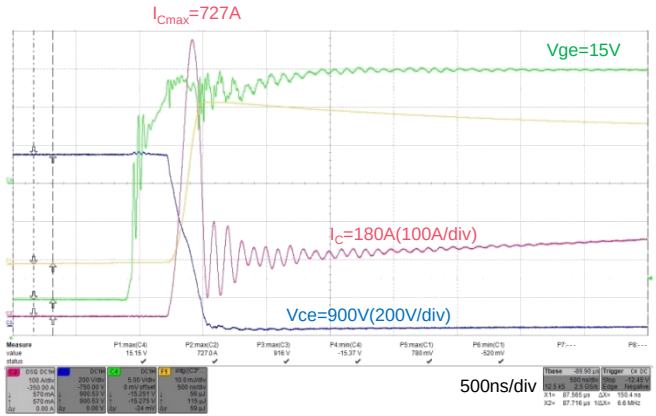
a) loop of ANPC-PWM1 b) PWM of ANPC-PWM1

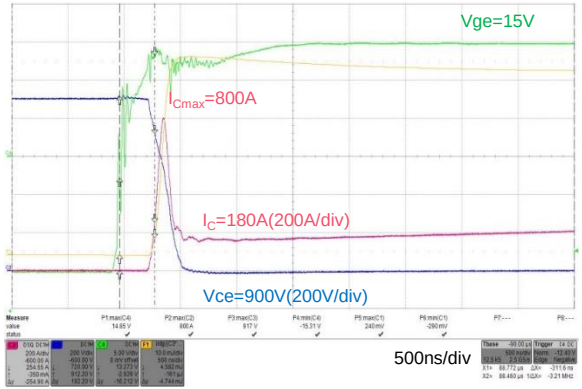
ANPC-PWM2

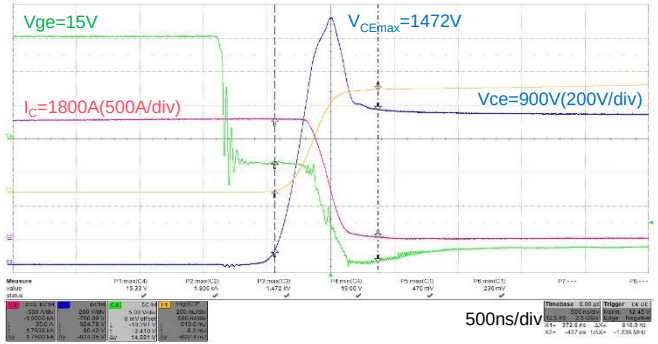


a) loop of ANPC-PWM2 b) PWM of ANPC-PWM2

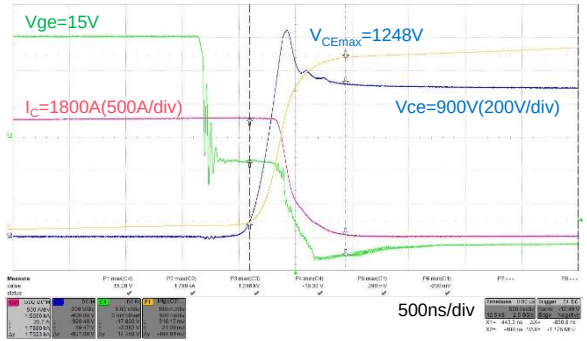
2. The PWM method of ANPC
The method for improving the commutation loop







a) Ls=81nH



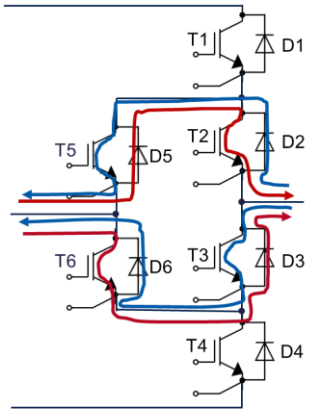
b) Ls=30nH

FF1800R17IP5

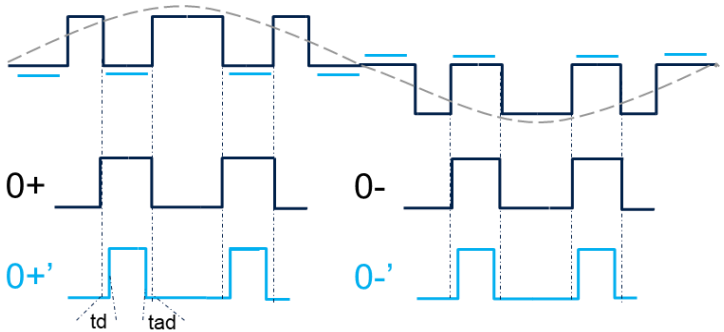
Test condition:

- Current (180A and 1800A),
- low temperature (25℃)
- and low gate resistor (@Ron=0R25)

2. The PWM method of ANPC
The method for total loss reduction

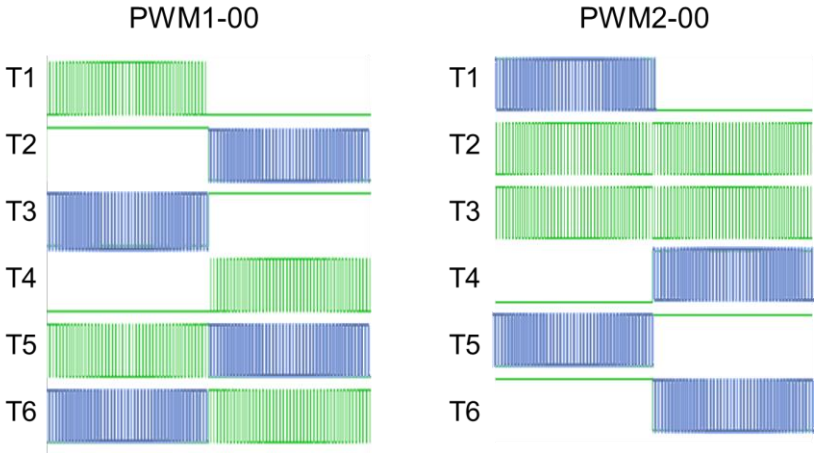


	ANPC
+1	T1→T2→ →D2→D1
0	T6→D3→ (New) D5→T2→ →T3→D6 →D2→T5 (New)
-1	→T3→T4 D4→D3→



The theory for using paralleling conduction paths in “0” state

ANPC PWM1-00 and PWM2-00



The switching PWM with double current paths in “0” state generated from PWM1 and PWM2 respectively

Improvement depends on:

- the modulation index (m)
- the power factor (cosφ)

2. The PWM method of ANPC
The method for balancing power losses

ANPC PWM-DF

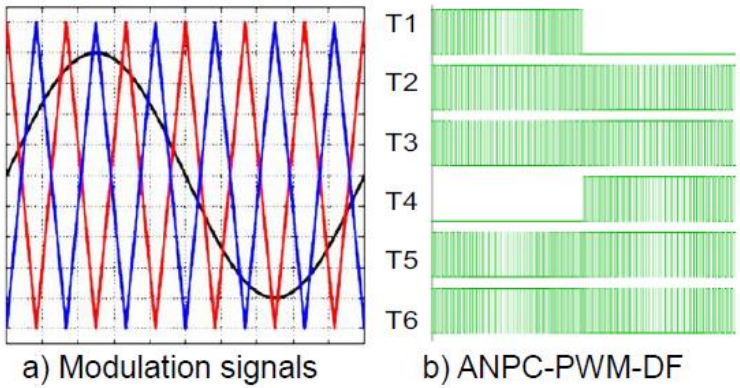


Fig 9. Double-frequency ANPC control

There are equal switching losses between inner switches and outer switches in the double frequency strategy, and similar conduction losses if the modulation index is close to one. Therefore, very similar losses for outer and inner switches can be achieved with DF ANPC control.

ANPC PWM-Hybrid

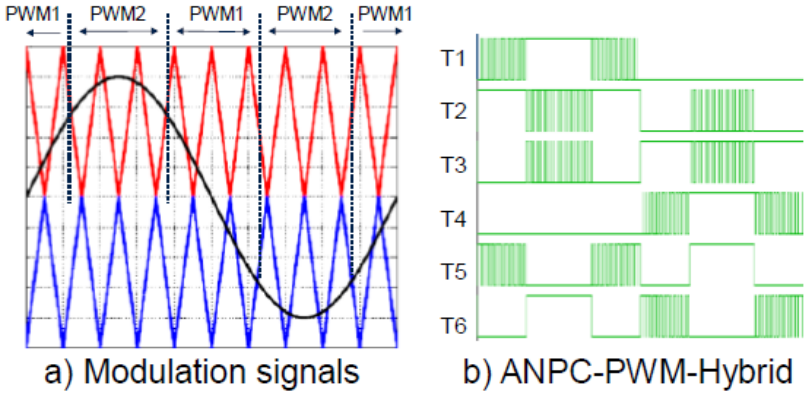


Fig 10. Hybrid PWM strategy for ANPC

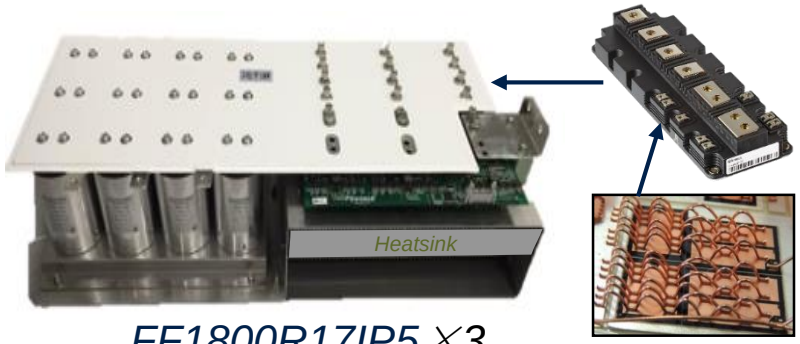
ANPC-PWM-ALD

There is an adjustable loss-distribution modulation called ANPC-PWM-ALD. Essentially, the “stress-out” mode =ANPC-PWM1 and the “stress-in” mode =ANPC-PWM2, only a slight difference in the switching sequences of the zero state.

3. Prototype and simulation - set up

Target application and a prototype concept in a power stack design

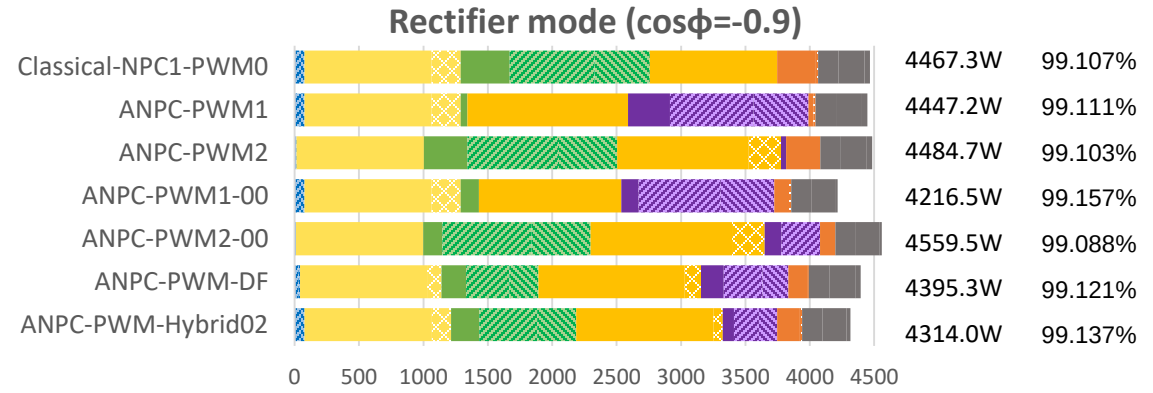
Application conditions	**Value** R.S | G.S
Power rating	3MW
DC-link voltage	1800V
Output voltage	1140V
Modulation index	1.03
Output current	1688A | 1519A
Line frequency	10Hz | 50Hz
Switching frequency	1.5kHz | 2kHz
Power factor	- 0.9 | +1
Heatsink maximum temperature (Liquid)	85℃



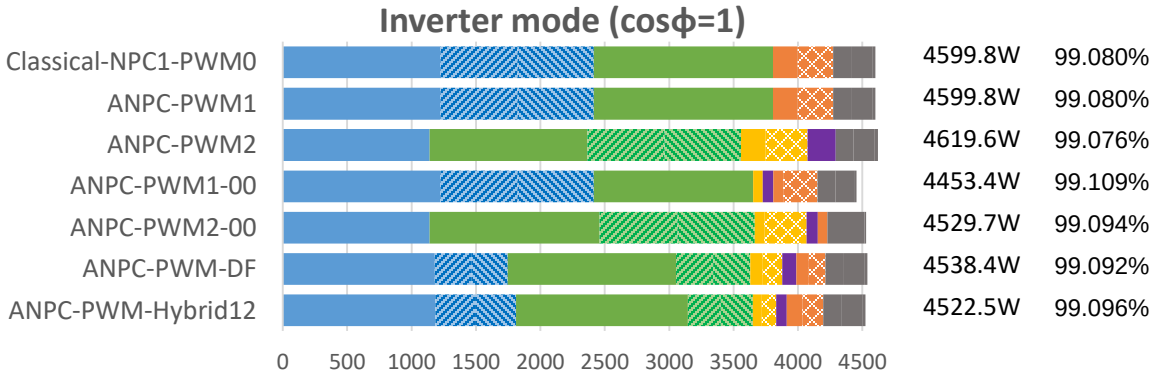
FF1800R17IP5 ×3

	PWM method	*Commutation loop*	*Paralleling paths*	*Loss balancing*
1	*Classical-NPC1-PWM*	*Uncertain*	*No*	*No*
2	*ANPC-PWM1*	*Short*	*No*	*No*
3	*ANPC-PWM2*	*Short²*	*No*	*No*
4	*ANPC-PWM1-00*	*Short*	*Yes*	*No*
5	*ANPC-PWM2-00*	*Short²*	*Yes*	*No*
6	*ANPC-PWM-DF*	*Uncertain*	*No*	*Yes*
7	*ANPC-PWM-Hybrid*	*Uncertain*	*No*	*Yes*

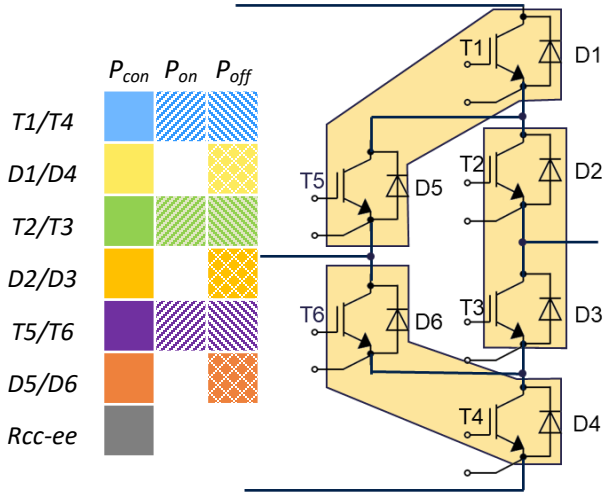
3. Prototype and simulation
- Power losses comparisons



Classical-NPC1-PWM0	4467.3W	99.107%
ANPC-PWM1	4447.2W	99.111%
ANPC-PWM2	4484.7W	99.103%
ANPC-PWM1-00	4216.5W	99.157%
ANPC-PWM2-00	4559.5W	99.088%
ANPC-PWM-DF	4395.3W	99.121%
ANPC-PWM-Hybrid02	4314.0W	99.137%

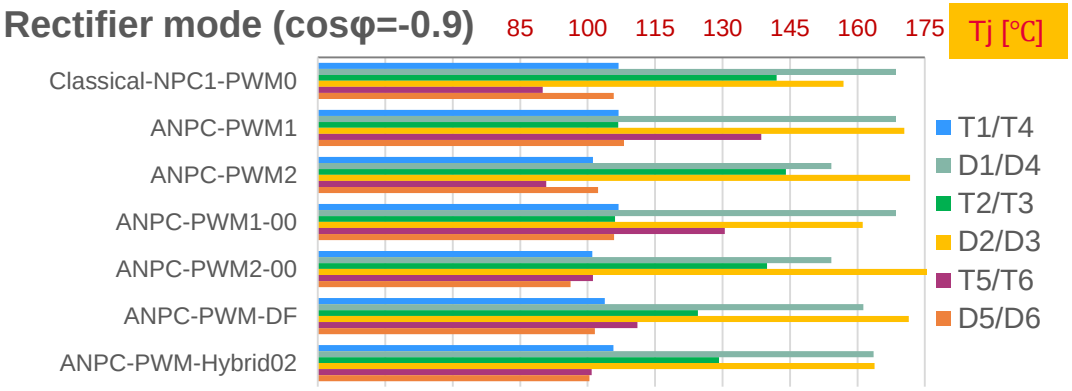


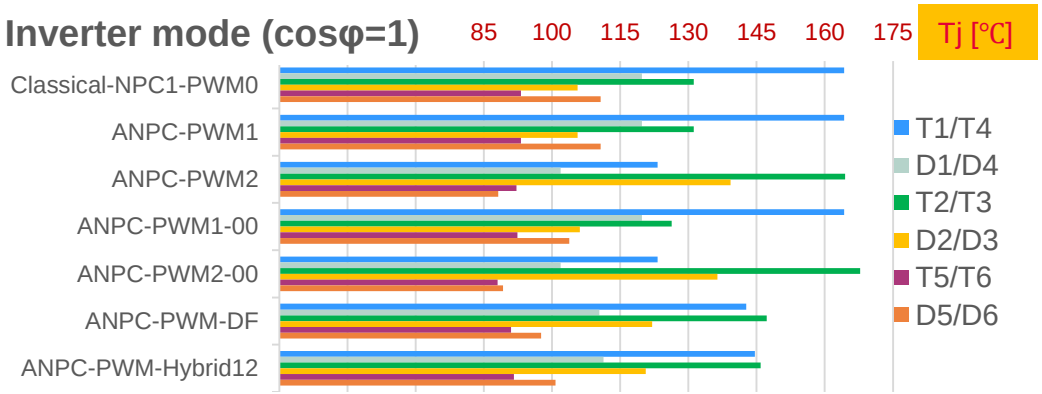
Classical-NPC1-PWM0	4599.8W	99.080%
ANPC-PWM1	4599.8W	99.080%
ANPC-PWM2	4619.6W	99.076%
ANPC-PWM1-00	4453.4W	99.109%
ANPC-PWM2-00	4529.7W	99.094%
ANPC-PWM-DF	4538.4W	99.092%
ANPC-PWM-Hybrid12	4522.5W	99.096%

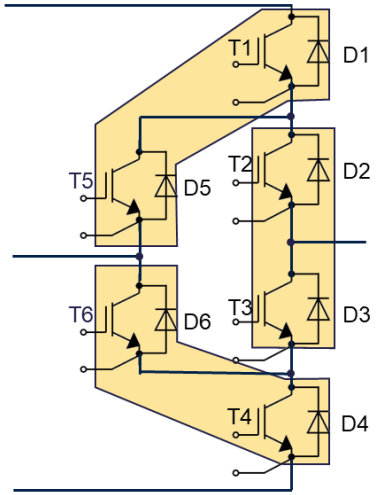


A 3L topology converter composed by 3pcs standard half-bridge IGBT modules

3. Prototype and simulation
- Junction temperature comparisons

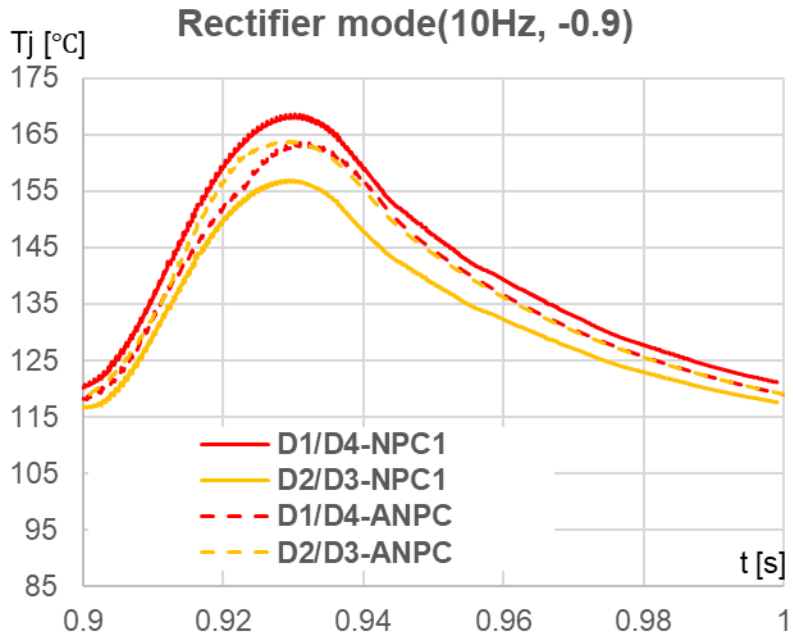


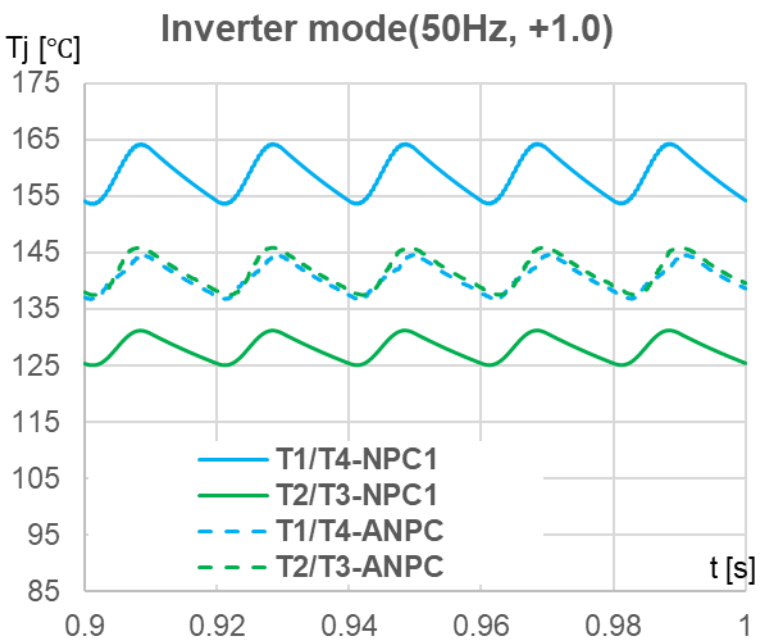




A 3L topology converter composed by 3pcs standard half-bridge IGBT modules

3. Prototype and simulation
- Junction temperature comparisons





The Tj waveform in 0.1s of top 2 hottest switches between NPC1 and ANPC (hybrid)

4. Conclusion

- **ANPC is a more flexible topology than NPC1**, and has special features to improve the converter performance, and it could maximize the utilization of standard half-bridge IGBT modules.

- **Seven PWM modulation methods are analyzed for different purposes.**
  - ANPC-PWM1 is the simplest method for avoiding long commutation loops
  - ANPC-PWM1-00 is the best method for improving system efficiency both in the rectifier mode or inverter mode.
  - ANPC-PWM-Hybrid will reduce the maximum junction temperature, or to increase the system output capability.

- **High junction temperature ripple would cause lifetime issue** of the power modules against cycling loads, therefore copper bond-wire joint technology is the best solution for addressing this challenge.

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