3-Level Gate Drive Design

Protection functions of gate driver board

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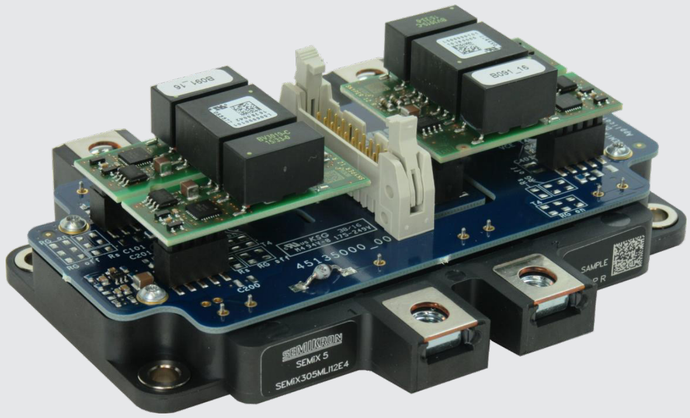

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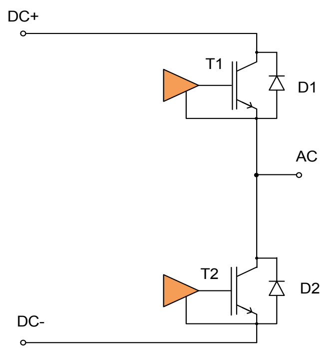
Driver Board Stages

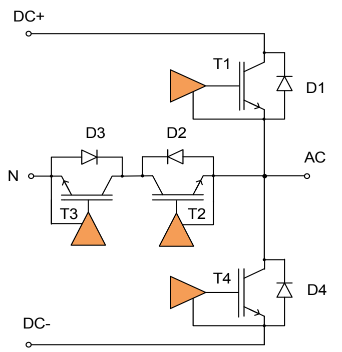
3-level topology is mainly used in solar applications, UPS and ESS.

In comparison to standard 2-level applications with two IGBT per phase need 3-level applications four IGBT per phase means also four driver stages.

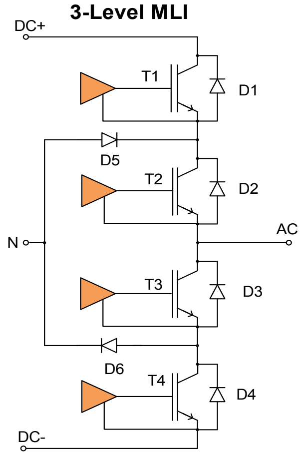
2-Level GB Type



3-Level TMLI



3-Level MLI



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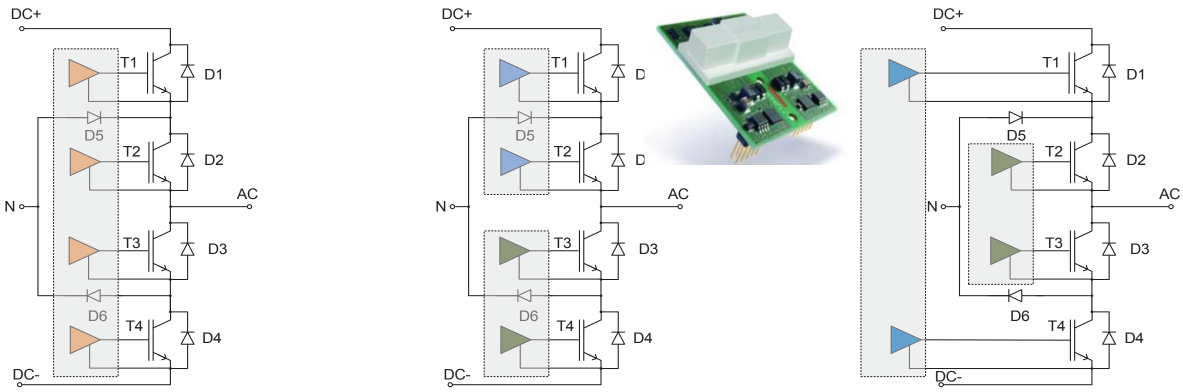
Driver Board Stages

All four drivers can be placed on one PCB but it is also common to use standard double stage output drivers and adapter boards to connect to the modules.

Essential for design of driver board is handling of **short circuit** and the **over voltage protection.**



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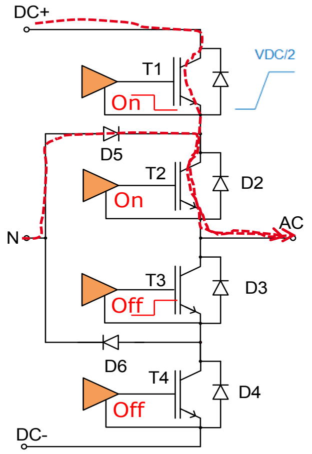
Switching Regime – MLI

For 3-level modules switch off regime has to be followed to protect modules for too high voltage.

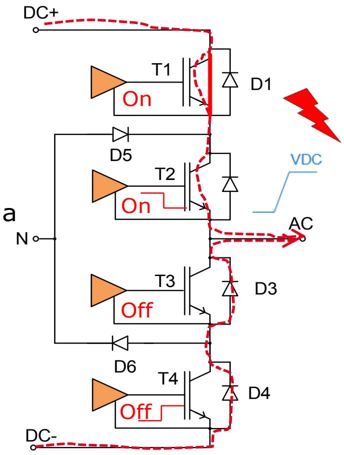
MLI and TMLI: Outer IGBT has to be switched off first.



Right:
Outer IGBT switches off first .

Free wheeling via diode D5.

VCE_T1=VDC/2



Wrong. Inner IGBT switches off first while outer IGBT is conducting.

Free wheeling via diode D3 and D4

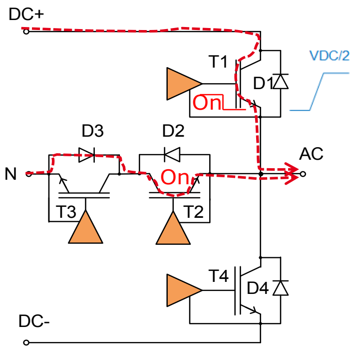
VCE_T2=VDC

Destructive when VDC is higher than IGBT blocking voltage.
Consider also peak voltage due to switching

Switching Regime – TMLI

Outer IGBT shall turn off first to commutate the current into the inner IGBT (horizontal circuit).

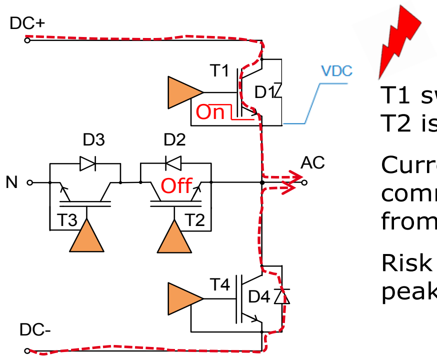
Wrong: T2 is already off when T1 switches off. In this case current commutates directly to D4. The steady voltage on T1 is VDC that the IGBT can withstand. But the peak voltage is higher than in normal commutation to the horizontal path because the commutation loop is longer.



Outer IGBT switches off first.

Freewheeling via D3, T2.

VCE_T1=VDC/2



T1 switches while T2 is already off.

Current commutates from T1 into D4.

Risk of too high peak voltage.

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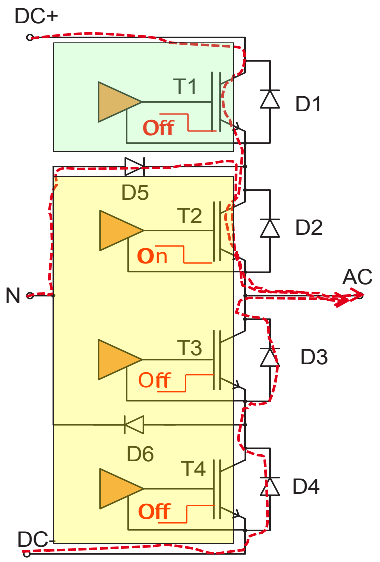
Peak Voltage Protection - MLI

T1/T4 requires usually no active clamping because of small commutation loop into D5/D6.

Active clamping on T2/T3 usually needed because T2/T3 switch off and commutation into D3/D4 leads to higher peak voltage due to long commutation.



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Peak Voltage Protection - TMLI

All IGBT have small commutation loop. So no switch has disadvantage in commutation (symmetrical layout considered).

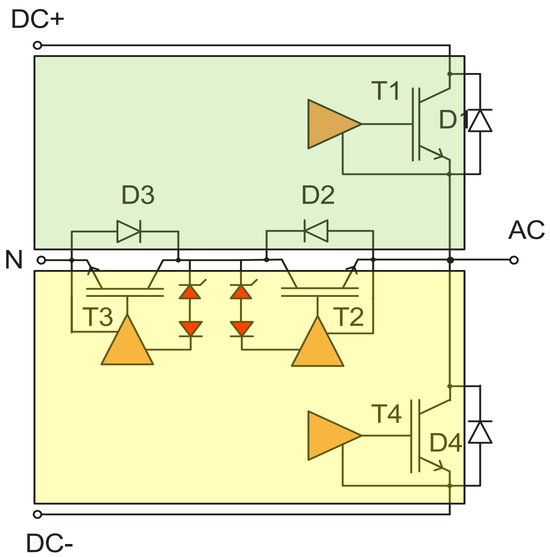
But active clamping on T2/T3 may be necessary because of lower voltage margin.

Example: Maximum DC bus voltage=900V.

T1/T4=1200V IGBT/Diode. Margin at switching 1200V-450V=750V.

T2/T3=650V IGBT/Diode. Margin at switching only 650V-450V=200V.

Peak voltage to be considered.



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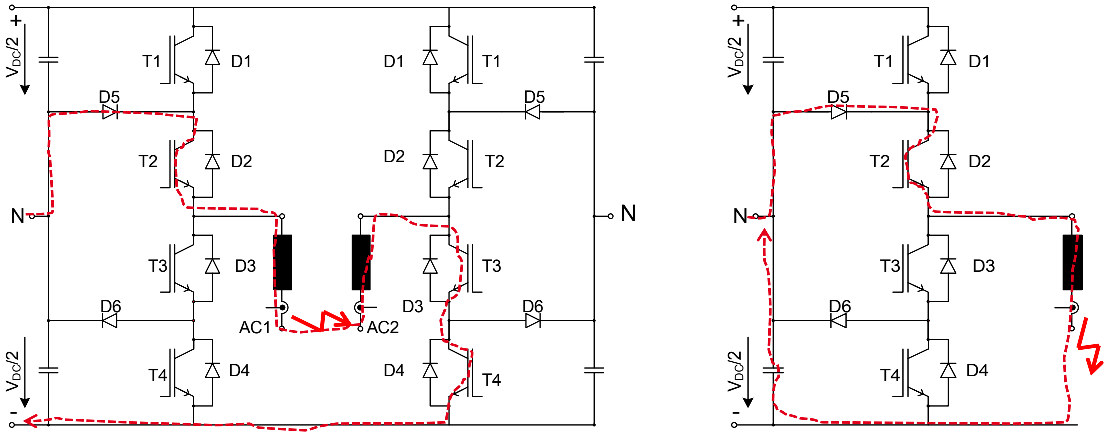
Short Circuit Case – SC after Line Filter

Short circuit line to line

Always outer IGBT and inner IGBT involved.

Short circuit line to DC

Possibly only inner IGBT or only outer IGBT involved.



Always current censor involved – Current Sensor will protect all short circuit !

Short Circuit Case – SC before Line Filter

Short circuit line to line

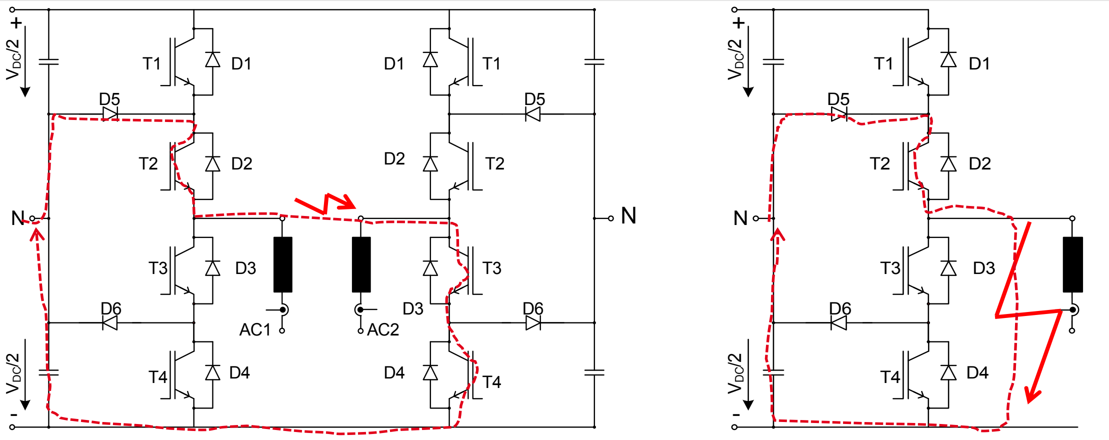
Always outer IGBT and inner IGBT involved.

DESAT protection on outer IGBT

Short circuit line to DC

Possibly only inner IGBT or only outer IGBT involved.

DEAT protection inner and outer IGBT



No current sensor involved – Need Vce Detection on Gate Driver

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No DESAT - Over Current Protection on Output

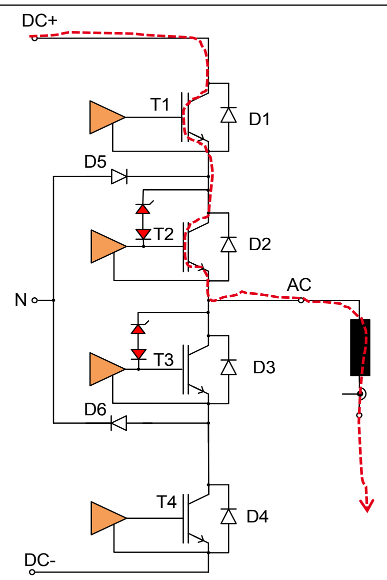
Over Current Protection only - no DESAT protection

Short circuit has to be switched off by over current protection from current transducer.

Consider switch off regime (always outer first).

No protection against SC which occurs inside the inverter before current sensor.

T2/T3 active clamping usually needed because of higher peak voltage due to long commutation loop.



MLI shown. But same for TMLI

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DESAT Outer IGBT MLI - Line-to-Line SC Protection

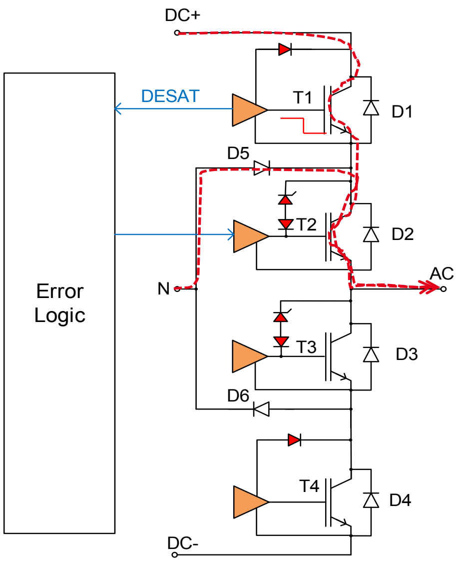
DESAT on outer IGBT (T1/T4)

Protection SC line to line not phase to DC-minus/ground.

Always outer IGBT T1/T4 involved.

Switch off T1/T4 by DESAT. Normal commutation as in inverter operation because T2 is on. Error signal to logic unit which switches off T2/T3 after T1/T4.

T2/T3 switching off at high current which makes active clamping usually necessary due to higher peak voltage by long commutation loop.



Desat T1: Switch off first T1 then T2

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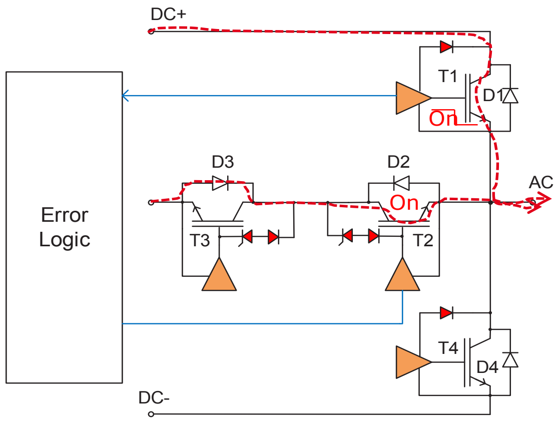
DESAT Outer IGBT TMLI - Line-to-Line SC Protection

DESAT on outer IGBT (T1/T4)

Same as MLI:

Switch off T1/T4 by DESAT. Normal commutation as in inverter operation because T2 is on. Error signal to logic unit which switches off T2/T3 after T1/T4.

T2/T3 switching off at high current which makes active clamping usually necessary because T2/T3 have small voltage margin.



Desat T1: Switch off first T1 then T2

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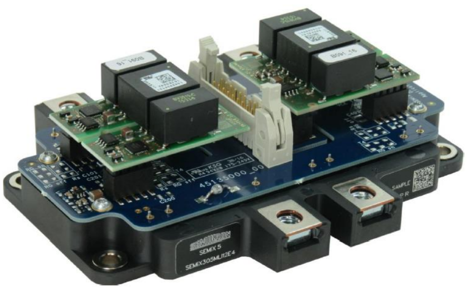
DESAT Outer IGBT - Line-to-Line SC Protection

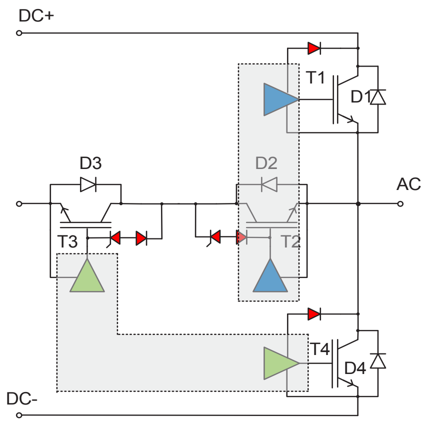
Application sample: SEMiX5 1200V MLI and TMLI. SKYPER12 Driver Board.

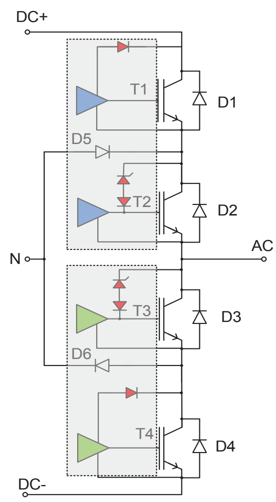
~120kW

One driver used for T1/T2 and the other for T3/T4.

Driver switches off at error but does not switch off complementary stage.







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3L SEMiX®5 Gate Drive and Adapter Card for Single Module

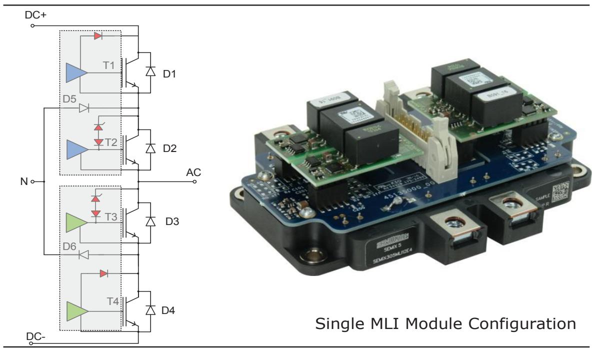
Module arrangement

- 1 x SEMiX5 NPC (650V, 150A- 400A)
- 1 x SEMiX5 NPC (1200V, 150A- 300A)

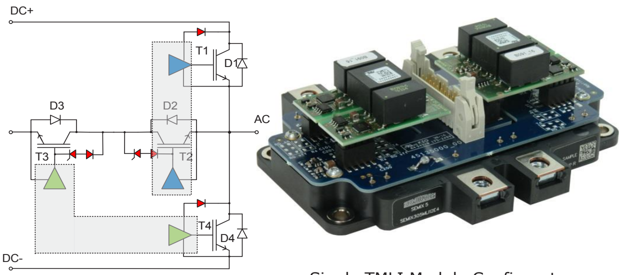
- 1 x SEMiX5 TNPC (1200V, 200A-400A)
- 1 x SEMiX5 TNPC (1700V, 200A-300A)

Driver board

- 2x SKYPER12 drive one phase leg
- One for T1/T2 and the other for T3/T4
- $V_{CE,sat}$ monitoring for outer IGBTs
- Active clamping for inner IGBTs
- Outer IGBTs turn-off by SC do not turn-off inner IGBTs automatically



Single MLI Module Configuration



Single TMLI Module Configurat on

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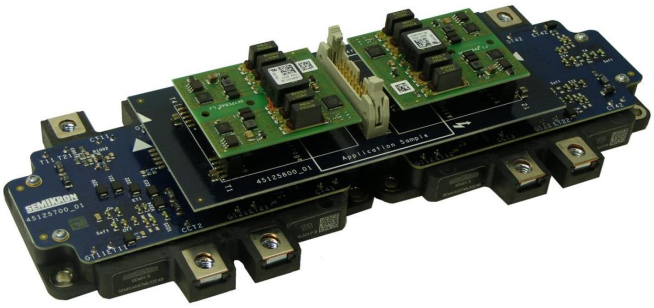
DESAT All IGBT TMLI – Full SC Protection

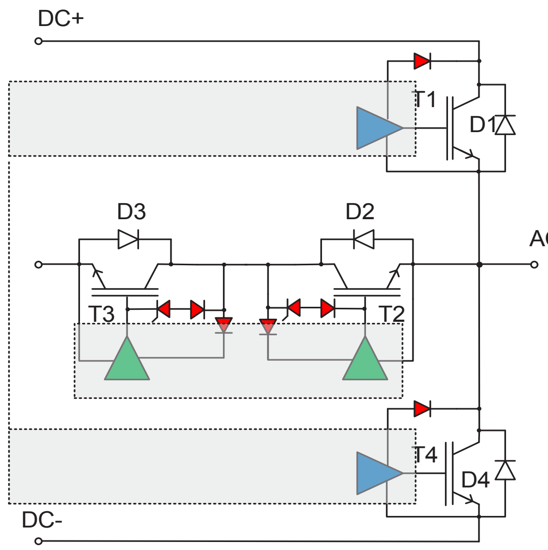
Application sample:

SEMiX5 1200V TMLI driver kit using SKYPER42LJ Driver Board. ~250kW

Two modules in parallel.

Driver board T2/T3 detects error but does not switch off.





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3L SEMiX®5 Gate Drive and Adapter Card for Module Parallel

Driver board

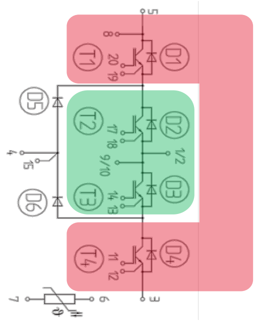
– 2x SKYPER42 drive one phase leg
– One for T1/T4 and the other for T2/T3
– Active clamping for inner IGBTs
– $V_{CE,sat}$ monitoring for all IGBTs, Low $V_{CE,sat}$ for T1/T4 and High $V_{CE,sat}$ for T2/T3

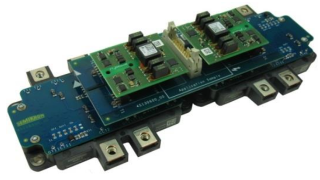
Outer switches(T1/T4) :

- Immediate turn-off of IGBT after V_{CE} detection with soft turn off.

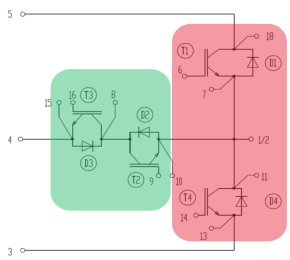
Inner switches(T2/T3) :

- Over-voltage protection by active clamping
- V_{CE} detection and warning message; no automatic turn-off. Turn-off must be handled by controller within 10us.





Dual MLI Module Configuration



Dual TMLI Module Configurat on

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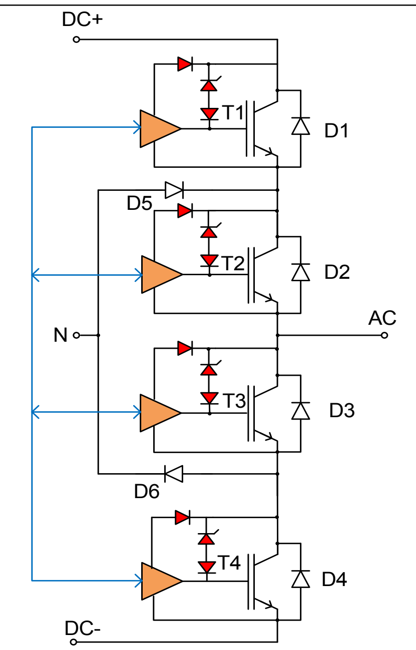
DESAT All IGBT MLI – Full SC Protection

Active clamping on all IGBT

In case of DESAT all IGBT can be switched off immediately without switch off regime.

T2/T3 can be switched off during conduction of T1/T4 (usually forbidden). The active clamping protects the IGBT.

Soft-off resistor not needed and not useful because of active clamping.



Linked biderectional error signal error signal

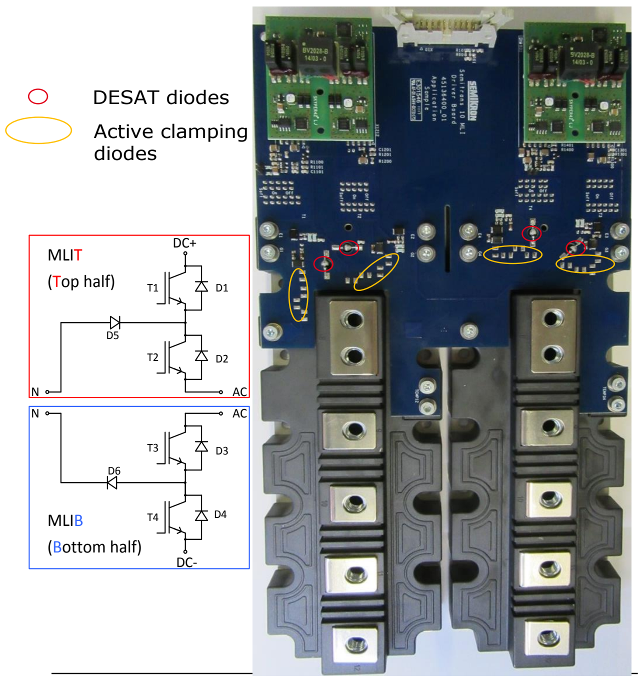
DESAT All IGBT MLI – Full SC Protection

Application sample:

SEMITRANS 10 split MLI topology. ~750kW

SKYPER42LJ driver used for T1/T4 and the other for T3/T4.

Driver switches off all IGBT on error. Bidirectional error signals connected.



ST10 Gate Drive and Adapter Card

Module arrangement

– SKM1200MLI12TE4 (1200V, 1200A)

– SKM1200MLI12BE4 (1200V, 1200A)

Driver board

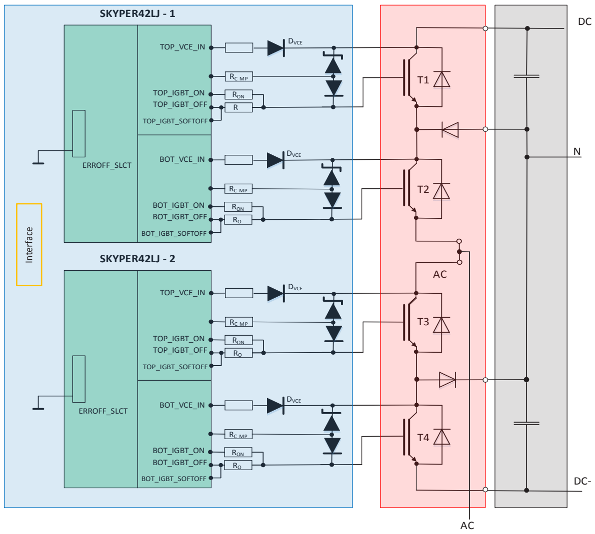
– 2x SKYPER42 LJ drive one phase leg

– $V_{CE,sat}$ monitoring and active clamping for all IGBTs

– Switch off IGBT which detected error immediately. Other IGBT are switched off by linked error signal.

– Wrong switching regime during operation is also protected. T2/T3 is allowed to switch off before T1/T4. In this case active clamping protects T2/T3.

– Full SC protection is possible : Phase to phase, Phase to DC



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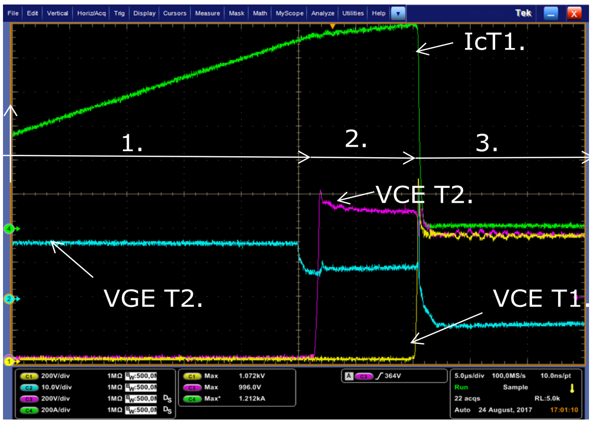
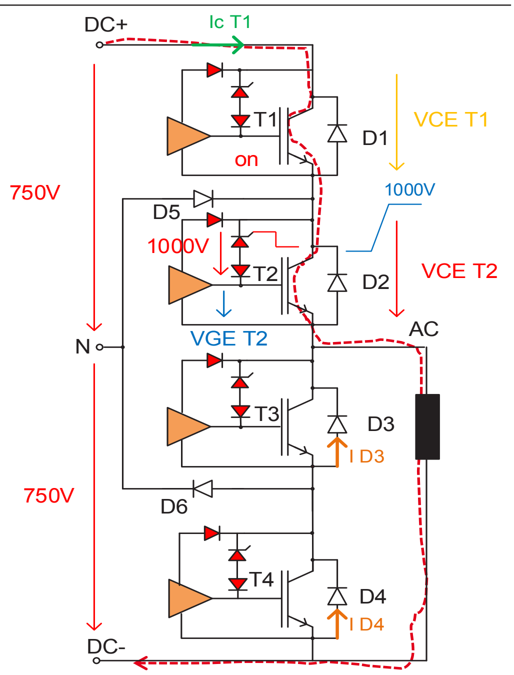
MLI - Active Clamping Test ST10

Active clamping operation at switch off T2 during conduction T1:

Waveform at testing with VDC=1500V Imax=1000A.





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MLI - Active Clamping Test ST10

Active clamping operation at switch off T2 during conduction T1

Operation: VDC=1500V. IGBT clamping voltage 1070V. Peak current 1000A. Inductor 70µH

1. T1 and T2 switched on. Inductor is rising di/dt=1500V/70µH=21,5A/µs
2. T1 should switch off and commutate load current into D5 in normal. But by error T2 switches off first. The voltage on T2 is rising to the active clamping voltage of 1070V peak.
   After the peak VCET2 is decreasing to 920V because the driver board stage has switched off and therefore current in clamping diodes is reduced.
   The voltage in inductor is decreasing to UL=1500V-920V=580V which leads to reduced steepness of current di/dt=580V/70µH=8A/µs
   T2 is operating in linear mode with high power losses (P=920V*960A).
   T1 has to clear this operation within several µs. In this test after 8µs.
3. T1 is switching off. The current commutates to D3 and D4. Current in T1 and T2 turns to 0A.

Content

Summary of OV and SC Protection

- Switching regime(T1/T4 turn-off first before T2/T3 turn-off) shall be followed to limit overvoltage protection design effort (active clamping). This sequence is recommended to be maintained at any time, like in case of emergency shut-down (e.g. because of over load, short circuit) and blackout.
- If DESAT detection is implemented on T2/T3, the error has to be sent to controller(FPGA/CPLD or MCU interrupt) which switches off T1/T4 first and then T2/T3.
- DESAT detection and active clamping on all IGBT is the proof against all SC events and wrong commutation. But this requires many components(especially TVS) and is therefore decreasing reliability.
- DESAT of only T1 and T4 with soft turn-off can protect all Line to Line SC.

Summary of OV and SC Protection

- MLI short circuit protection is more critical because of two IGBTs in series at desaturation interact each other, means that lead to oscillations and finally can cause destruction.
- MLI active clamping on T2/T3 is recommended because T2/T3 have long commutation loop and abnormal turn-off sequence(T2/T3 turn-off first before T1/T4 turn-off) can arise high VCE(higher than VDC) on T2/T3.
- TMLI active clamping on T2/T3 is recommended because T2/T3 have small voltage margin.
- It is recommended to check closely which protection functions are needed. For short circuit outside inverter the DESAT protection is usually not needed. Over current protection function from current sensor is usually sufficient.

References

[1] www.SEMIKRON.com
[2] A. Wintrich, U. Nicolai, W. Tursky, T. Reimann, “Application Manual Power Semiconductors”, 2nd edition, ISLE Verlag 2015, ISBN 978-3-938843-83-3
[3] I. Staudt et al, “Numerical loss calculation and simulation tool for 3L NPC converter design”, PCIM Nuremberg, 2011
[4] I. Staudt, “3L NPC & TNPC Topology”, SEMIKRON Application Note, AN11001 – rev05, Nuremberg, 2015

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