Application Note
AN 15-002

SEMIKRON DANFOSS

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How to Read a Semikron Danfoss 3L Datasheet

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1. General

The aim of this Application Note is to point out the most important differences and special features of 3-Level (3L) NPC, TNPC, and ANPC datasheets compared to 2-Level (2L).
A general explanation and derivation of all datasheet values is not intended; this information can be found in the “Application Manual Power Semiconductors” [2] or in particular Technical Explanations.

2. Theoretical Groundwork

2.1 Definition

The following list shows abbreviations and terms for 3L devices that are used in Semikron Danfoss datasheets, Technical Explanation, Application Notes and other documents:

NPC	**N**eutral **P**oint **C**lamped; describes the 3L NPC topology
TNPC	**T**-type **N**eutral **P**oint **C**lamped; describes the 3L TNPC topology

ANPC	**A**ctive **N**eutral **P**oint **C**lamped; describes the 3L ANPC topology
MLI	**M**ulti-**L**evel **I**nverter; is used as family name of 3L modules in NPC topology
TMLI	**T**-type **M**ulti-**L**evel **I**nverter; is used as family name of 3L modules in TNPC topology
AMLI	**A**NPC-type **M**ulti-**L**evel **I**nverter; is used as family name of 3L modules in NPC topology
Tx / Dx	Describes the position of the particular switch within the 3L topology where x is a number between 1 and 6; T refers to a transistor, D refers to a diode;
IGBT1	Represents transistors T1 and T4 in Semikron Danfoss NPC and TNPC datasheets, represents T1, T4, T5, and T6 in Semikron Danfoss ANPC datasheets
IGBT2	Represents transistors T2 and T3 in Semikron Danfoss datasheets
Diode1	Represents diodes D1 and D4 in Semikron Danfoss datasheets
Diode2	Represents diodes D2 and D3 in Semikron Danfoss datasheets
Diode5	Represents diodes D5 and D6 in Semikron Danfoss datasheets (NPC topology only)
Outer switches	Refers to T1, T4, D1, and D4 (in other words: IGBT1 and Diode1) in NPC and TNPC
Inner switches	Refers to T2, T3, D2, and D3 (in other words: IGBT2 and Diode2) in NPC and TNPC
Clamping diodes	Refers to D5 and D6 (in other words: Diode5) in NPC
Input stage	T1, T4, T5, and T6 in ANPC
Output stage	T2 and T3 in ANPC

2.2 3L PWM pattern

2.2.1 PWM generation

All Semikron Danfoss 3L datasheets and calculations are based on a PWM pattern derived by using the sine-triangular comparison.
In short, the amplitudes of two triangular waves are compared with the amplitude of one sine wave. The result of the comparison (e.g. *sine > triangular_1 & sine < triangular_2*) defines the switching states of the 3-Level module's IGBTs. Further information is given for example in [3] and [4].

2.2.2 PWM restrictions

This abovementioned comparison results in a set of rules that are to be maintained at any time for NPC and TNPC:

1. A maximum of two switches may be turned on at the same time,
2. Only two adjacent switches may be turned on at the same time,
3. Switches T1 and T3 as well as switches T2 and T4 switch inversely.

Further considerations (explained in AN11-001, [4]) lead to additional rules:

4. Start of operation: inner switches (T2 or T3) must be turned on first, outer switches (T1 or T4) afterwards.
5. End of operation: outer switches (T1 or T4) must be turned off first, inner switches (T2 or T3) afterwards.

For ANPC the rules are simpler:

1. Only two combinations of two simultaneously turned-on switches of the input stage are allowed: T1 and T6 or T5 and T4
2. T1 + T6 and T4 + T5 switch inversely.
3. Additionally, one switch of the output stage may be turned on, either T2 or T3

Although some of the restrictions seem to make no sense at a first glance (e.g. an IGBT is turned on while it is not conducting; an example is given in Figure 22, image on right) it does indeed make a big difference in the resulting datasheet values.

Semikron Danfoss datasheet measurements and simulations are based on the rules derived by the sine-triangular comparison. As long as the PWM pattern is identical of course, other methods can be used.
Note: If these rules are not met, Semikron Danfoss datasheet values or simulation results are possibly not correct!

2.3 Commutation

When a semiconductor is turned off actively during normal operation (i.e. the PWM pulse ends) a current has been flowing through that device. Because of the turn-off the previous current path is no longer existent and as a current is not intended to be stopped, it needs to be passed on to another semiconductor. This process of passing the current flow from one to another path is called commutation.

2.3.1 NPC commutation

Figure 1 shows the current paths (left and centre image) of operating area 1 (positive output voltage and current) that alternate with the switching frequency. The image on the right shows the resulting commutation loop in blue colour.
Figure 2 shows the current paths and the commutation loop of operating area 3. In this operating area output current and voltage are negative.
The commutation in these two operating areas is geometrically rather short and therefore called "short commutation loop".
Figure 3 shows the current paths (left and centre image) of operating area 2 (negative output voltage and positive output current) that alternate with the switching frequency. The image on the right shows the resulting commutation loop in blue colour.
Figure 4 shows the current paths and the commutation loop of operating area 4. In this operating the output current is negative and the output voltage positive.
The commutation in these two operating areas is geometrically much longer than those of operating areas 1 and 3 and is therefore called "long commutation loop".

Figure 1: NPC current paths (red) and commutation loop (blue) for operating area 1

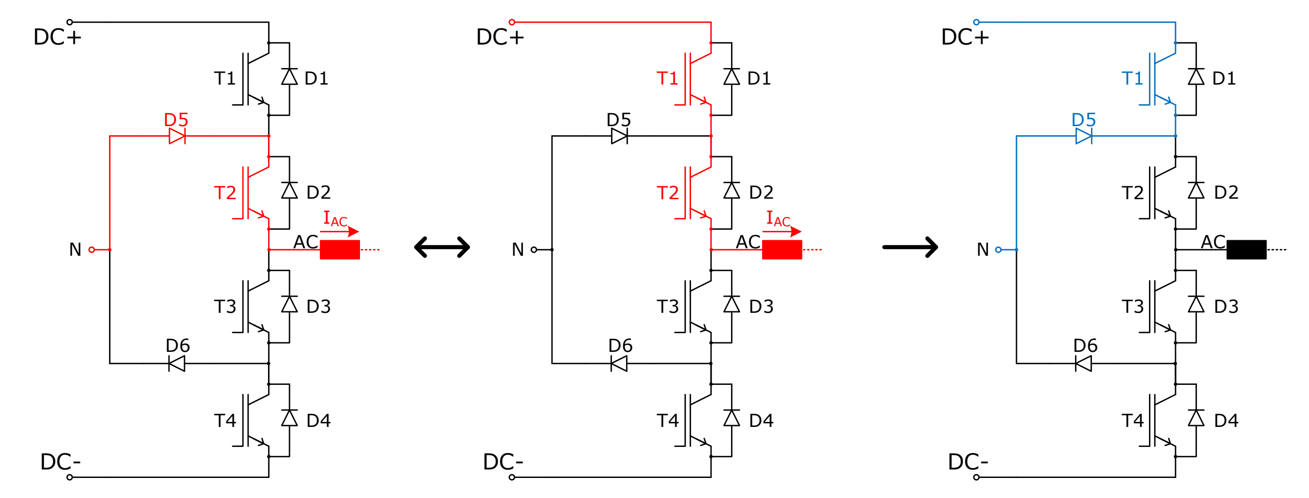


Figure 2: NPC current paths (red) and commutation loop (blue) for operating area 3

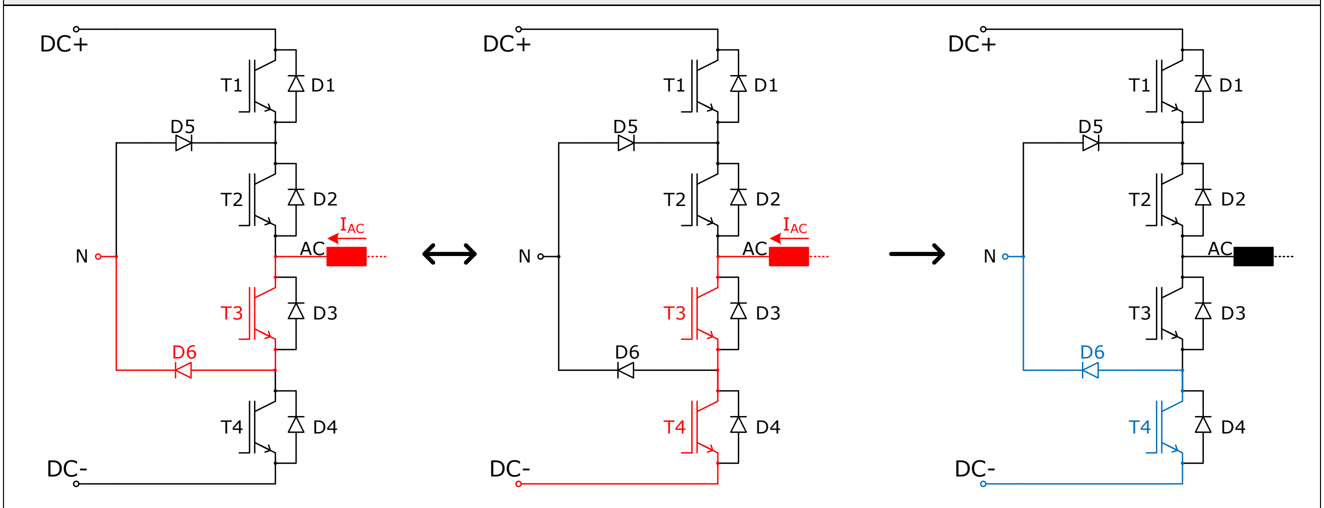


Figure 3: NPC current paths (red) and commutation loop (blue) for operating area 2

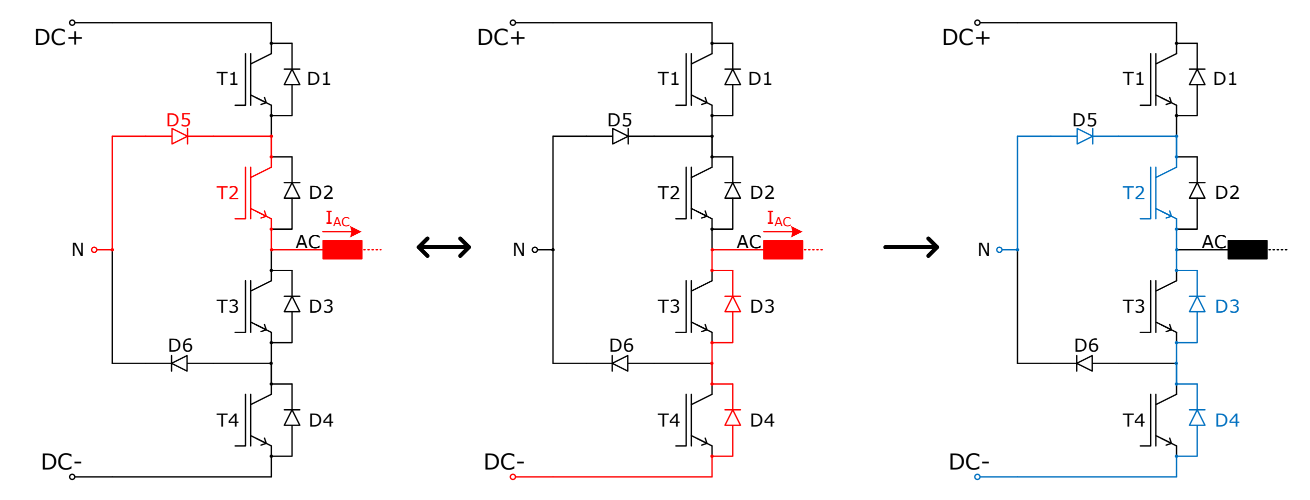
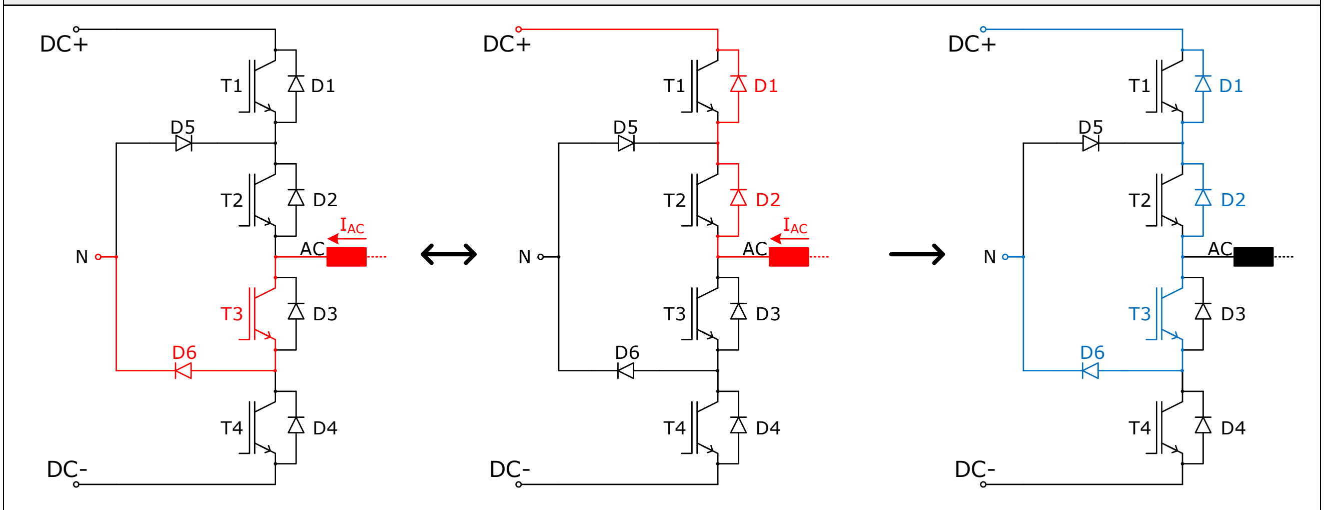


Figure 4: NPC current paths (red) and commutation loop (blue) for operating area 4



2.3.2 TNPC commutation

Figure 5 shows the current paths (left and centre image) of operating area 1 (positive output voltage and current) that alternate with the switching frequency. The image on the right shows the resulting commutation loop in blue colour.
Figure 6 shows the current paths and the commutation loop of operating area 3. In this operating area output current and voltage are negative.
By analogy with NPC the commutation in these two operating areas is called "short commutation loop".

Figure 7 shows the current paths (left and centre image) of operating area 2 (negative output voltage and positive output current) that alternate with the switching frequency. The image on the right shows the resulting commutation loop in blue colour.
Figure 8 shows the current paths and the commutation loop of operating area 4. In this operating area the output current is negative and the output voltage positive.
By analogy with NPC the commutation in these two operating areas is called "long commutation loop".

Figure 5: TNPC current paths (red) and commutation loop (blue) for operating area 1

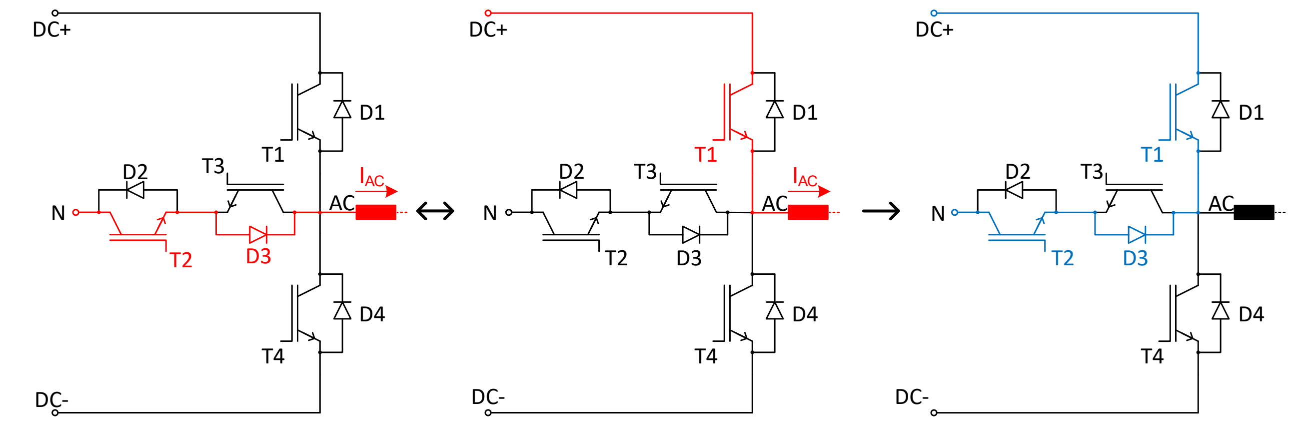


Figure 6: TNPC current paths (red) and commutation loop (blue) for operating area 3

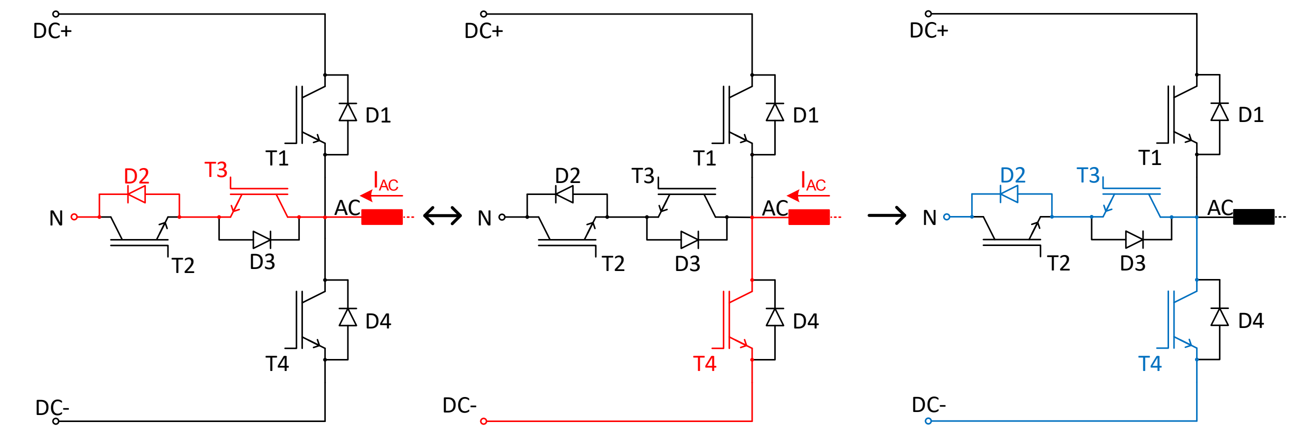


Figure 7: TNPC current paths (red) and commutation loop (blue) for operating area 2

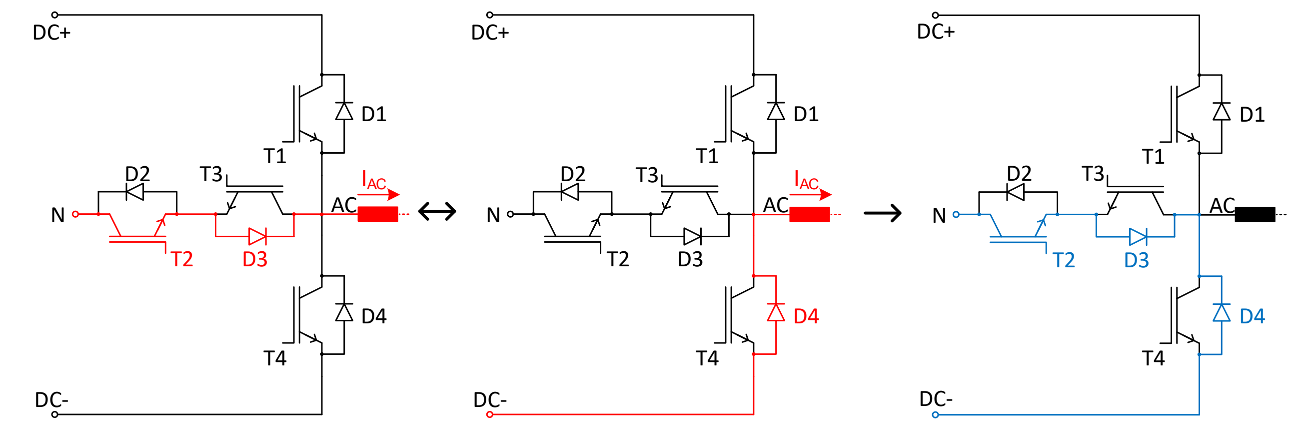
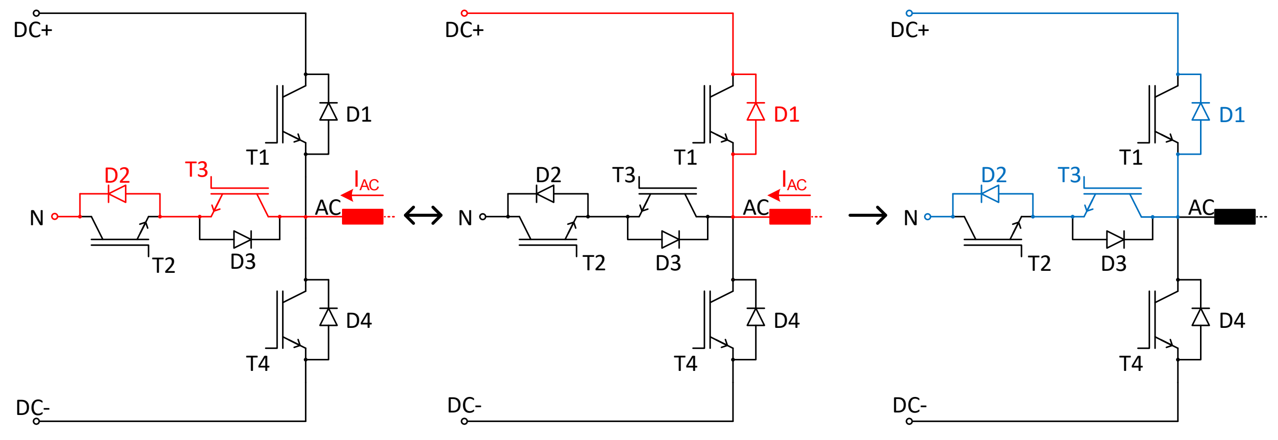


Figure 8: TNPC current paths (red) and commutation loop (blue) for operating area 4



2.3.3 ANPC HF/LF commutation

Figure 9 shows the current paths (left and centre image) of operating area 1 (positive output voltage and current) that alternate with the switching frequency. The image on the right shows the resulting commutation loop in blue colour.
Figure 11 shows the current paths and the commutation loop of operating area 2. In this operating area output current and voltage are negative.
Figure 12 shows the current paths (left and centre image) of operating area 3 (negative output voltage and positive output current) that alternate with the switching frequency. The image on the right shows the resulting commutation loop in blue colour.
Figure 14 shows the current paths and the commutation loop of operating area 4. In this operating the output current is negative and the output voltage positive.
The commutations in these four operating areas are geometrically rather short and therefore called "short commutation loops".
In case an ANPC HF/LF is built with three standard 2L modules (module 1: T1 and T5, module 2: T6 and T4, module 3: T2 and T3), the short commutation loops are each located within one of the 2L modules.

Figure 10 and Figure 13 show the transitions from either operating are 1 to operating are 2 or from operating area 3 to operating area 4. Left and centre images show the current paths in red colour, the right images show the resulting commutation loops in blue colour.
The commutation in these four transitions is geometrically much longer than those of the four operating areas and are therefore called "long commutation loops".
In case an ANPC HF/LF is built with three standard 2L modules (module 1: T1 and T5, module 2: T6 and T4, module 3: T2 and T3), the long commutation loops include all three 2L modules.

Figure 9: ANPC HF/LF current paths (red) and commutation loop (blue) for operating area 1

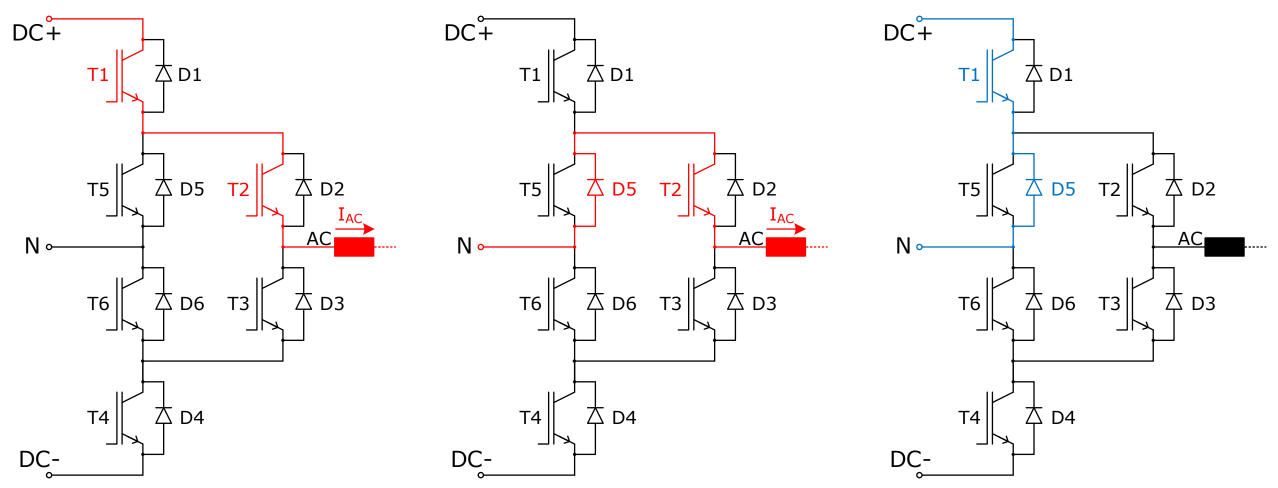


Figure 10: ANPC HF/LF current paths (red) and commutation loops (blue) for transitions from operating area 1 to operating area 2

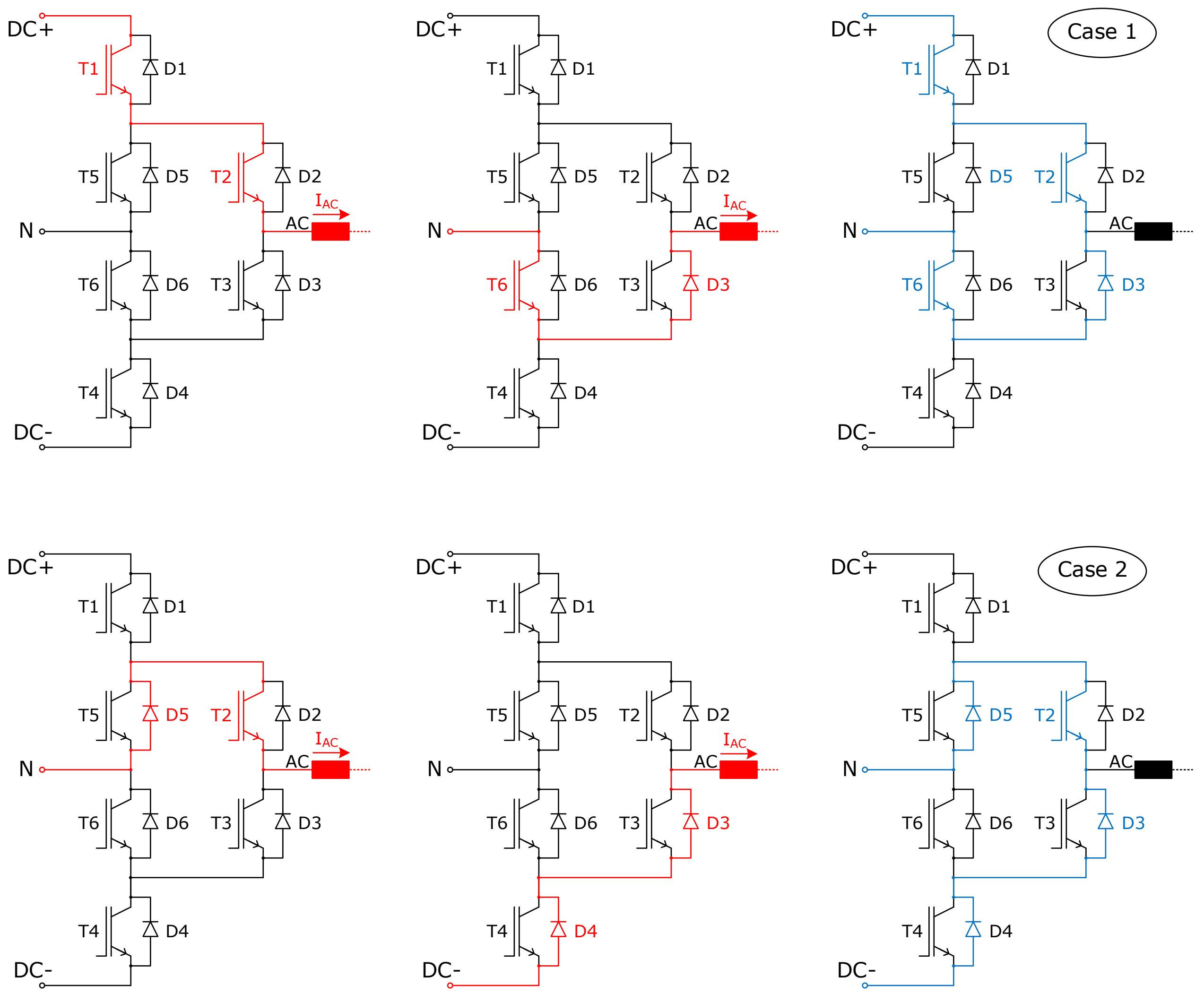


Figure 11: ANPC HF/LF current paths (red) and commutation loop (blue) for operating area 2

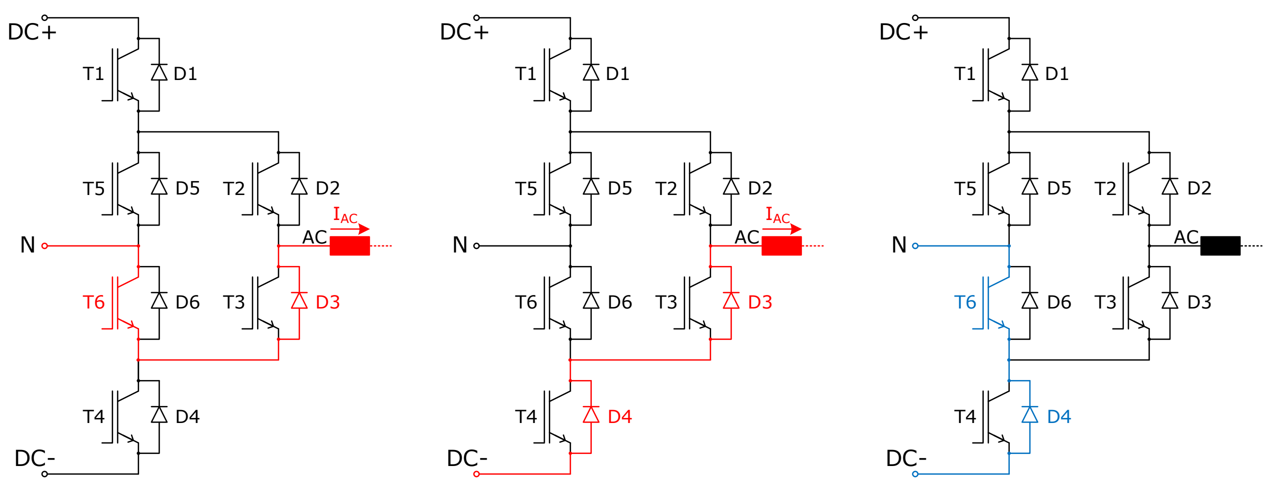


Figure 12: ANPC HF/LF current paths (red) and commutation loop (blue) for operating area 3

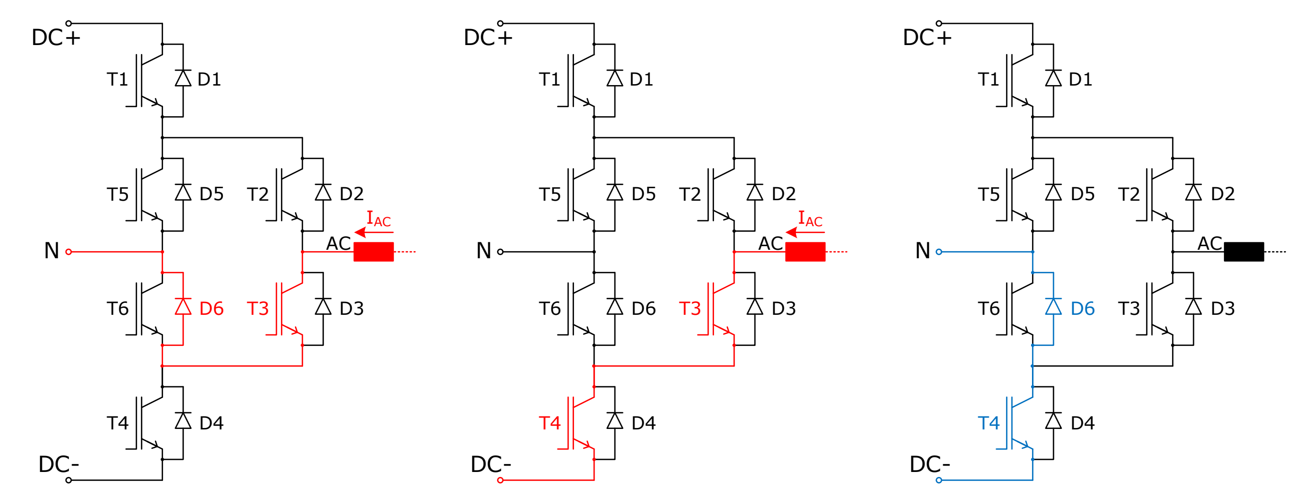


Figure 13: ANPC HF/LF current paths (red) and commutation loops (blue) for transitions from operating area 3 to operating area 4

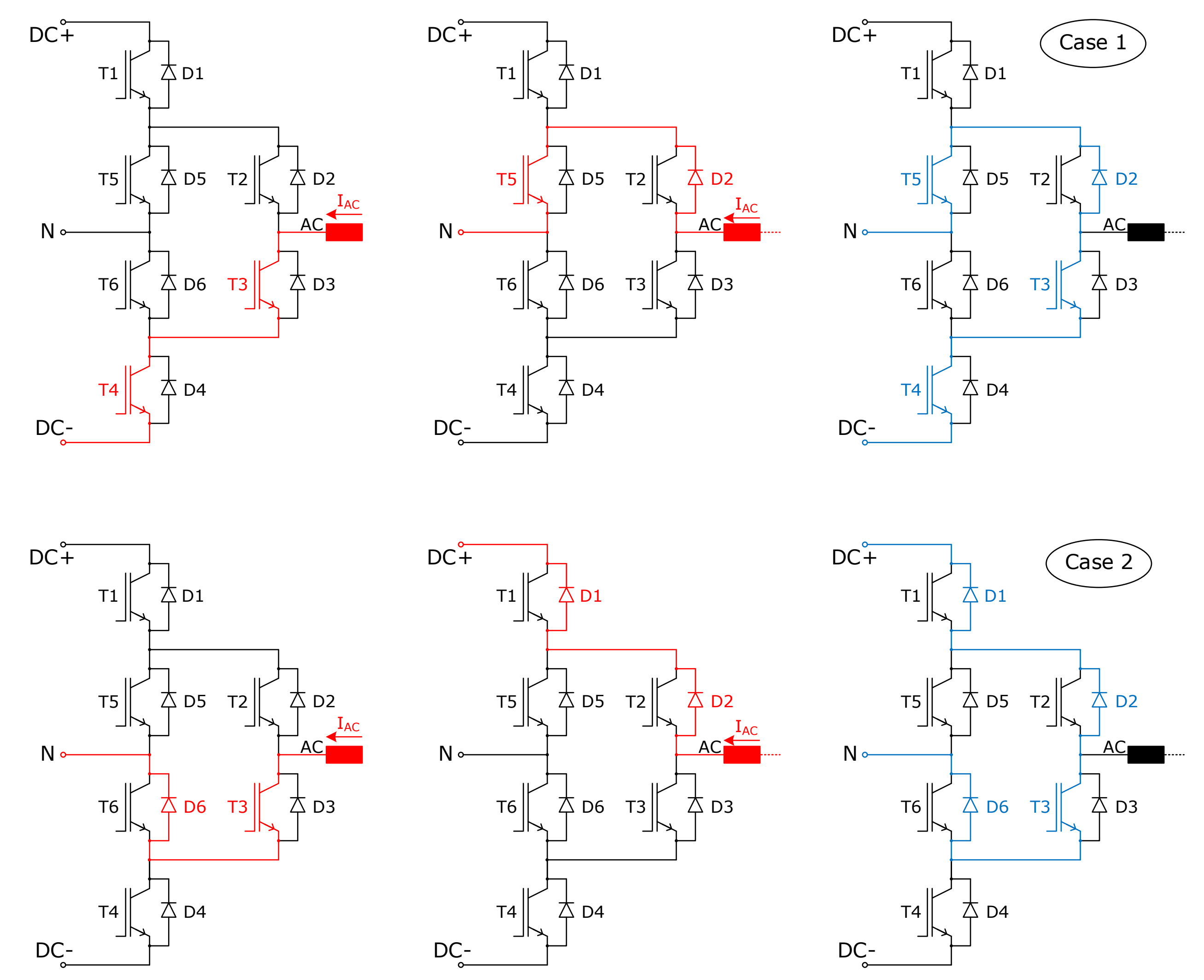
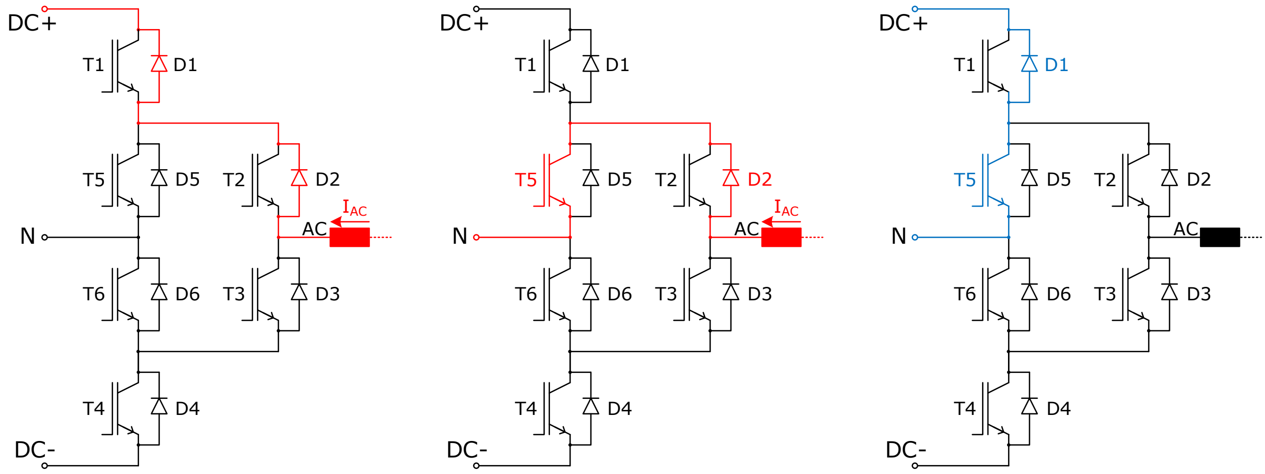


Figure 14: ANPC HF/LF current paths (red) and commutation loop (blue) for operating area 4



2.3.4 ANPC LF/HF commutation

Figure 15 shows the current paths (left and centre image) of operating area 1 (positive output voltage and current) that alternate with the switching frequency. The image on the right shows the resulting commutation loop in blue colour.
Figure 17Figure 11 shows the current paths and the commutation loop of operating area 2. In this operating area output current and voltage are negative.
Figure 18Figure 12 shows the current paths (left and centre image) of operating area 3 (negative output voltage and positive output current) that alternate with the switching frequency. The image on the right shows the resulting commutation loop in blue colour.
Figure 20 shows the current paths and the commutation loop of operating area 4. In this operating the output current is negative and the output voltage positive.
The commutations in these four operating areas are geometrically rather long and therefore called "long commutation loops".
ANPC LF/HF is not suitable for being set up from standard 2L modules as all the commutations with switching frequency take place across module boundaries and hence inherit a large stray inductance. ANPC LF/HF needs to be set up in a dedicated semiconductor module that inherits the whole topology.

Figure 16 and Figure 19 show the transitions from either operating are 1 to operating are 2 or from operating area 3 to operating area 4. Left and centre images show the current paths in red colour, the right images show the resulting commutation loops in blue colour.
The commutation in these four transitions is geometrically rather short compared to those of the four operating areas and are therefore called "short commutation loops".

Figure 15: ANPC LF/HF current paths (red) and commutation loop (blue) for operating area 1

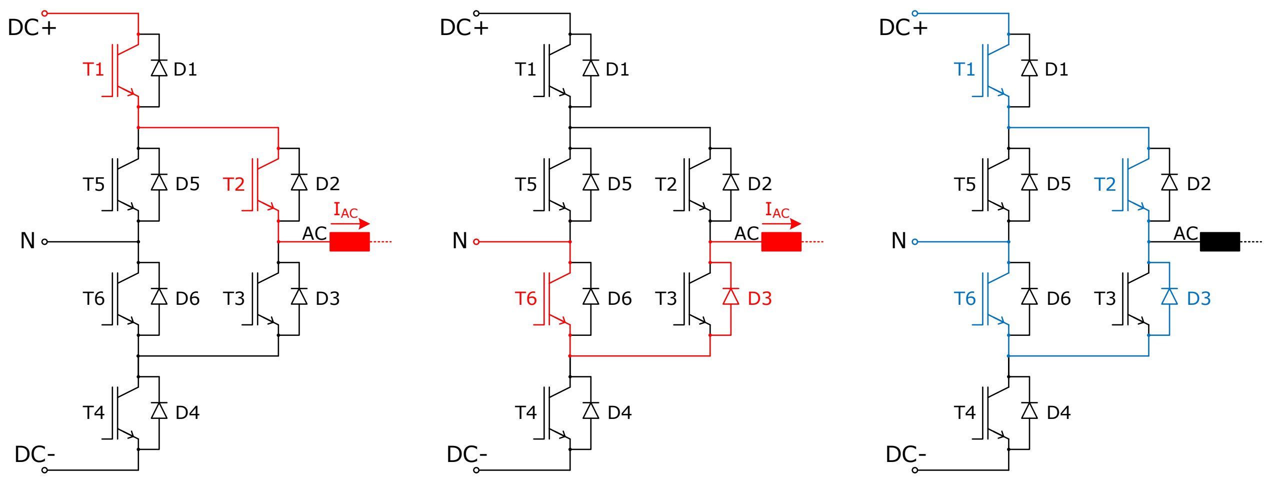


Figure 16: ANPC LF/HF current paths (red) and commutation loops (blue) for transitions from operating area 1 to operating area 2

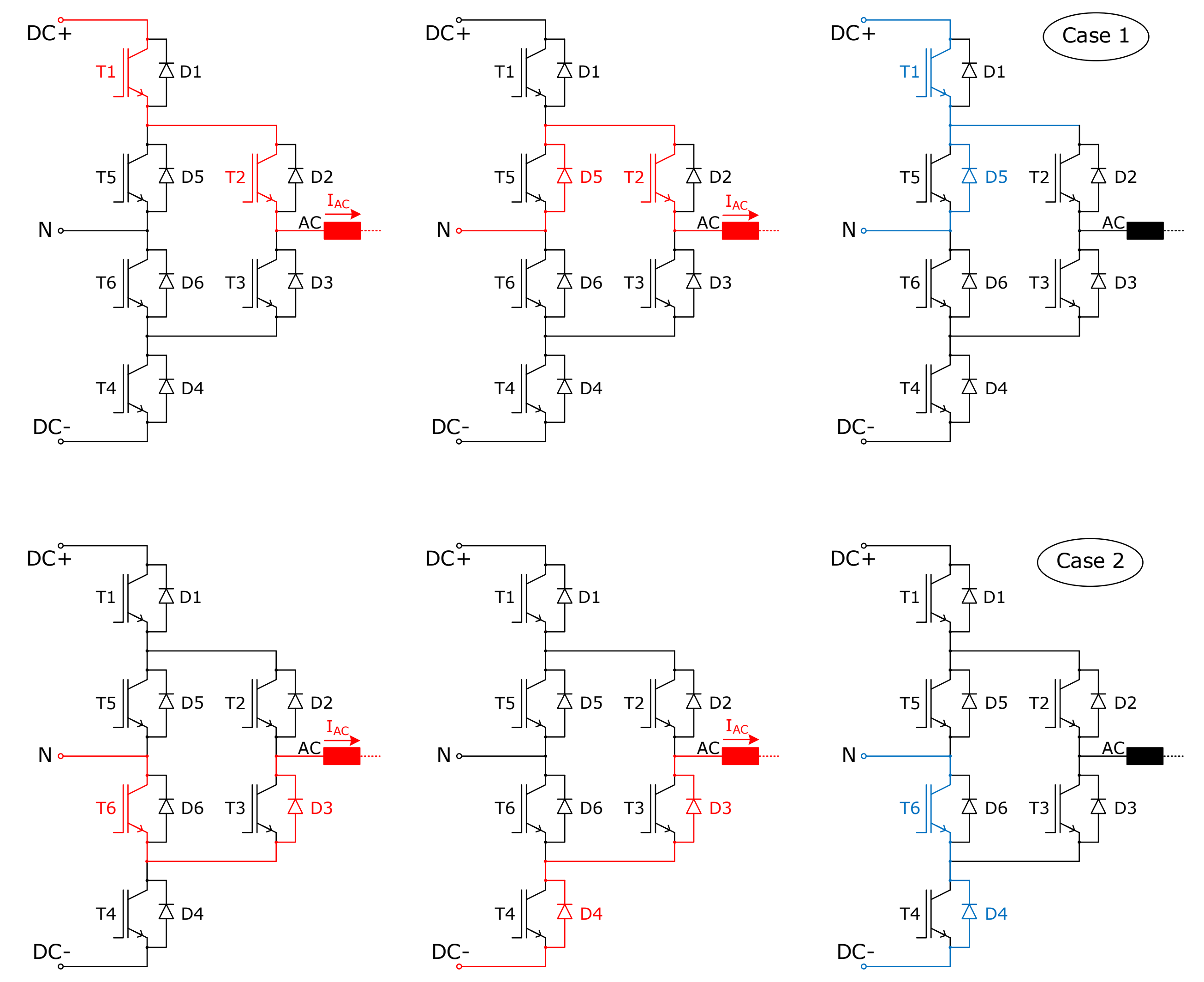


Figure 17: ANPC LF/HF current paths (red) and commutation loop (blue) for operating area 2

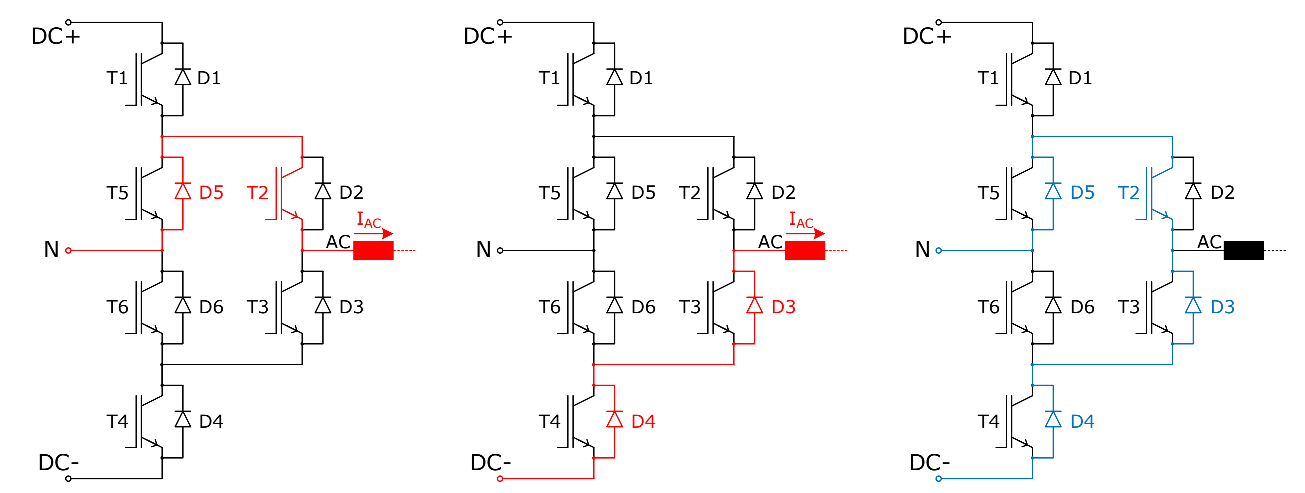


Figure 18: ANPC LF/HF current paths (red) and commutation loop (blue) for operating area 3

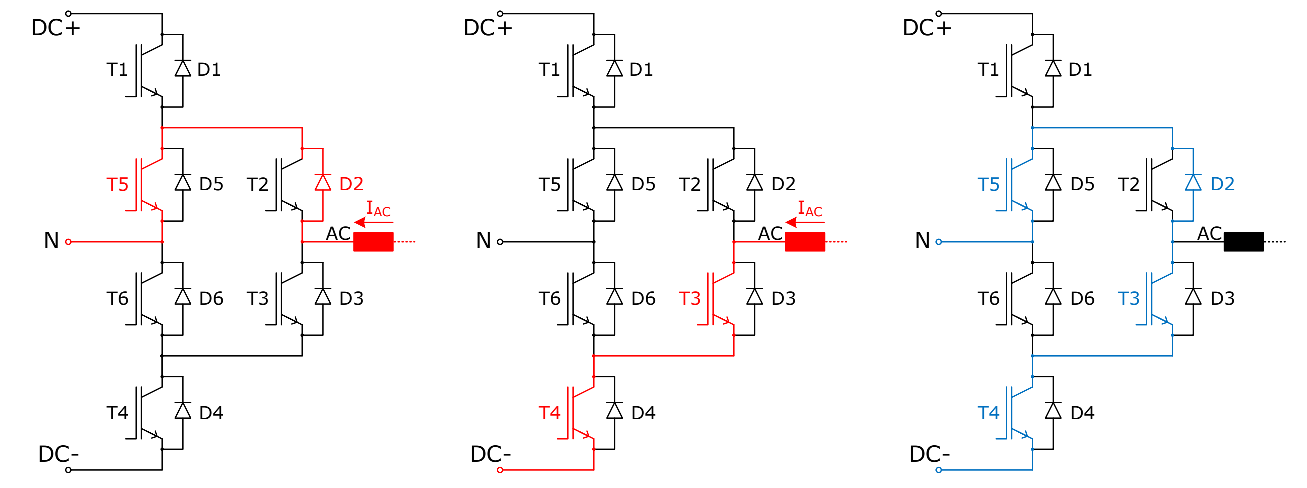


Figure 19: ANPC LF/HF current paths (red) and commutation loops (blue) for transitions from operating area 3 to operating area 4

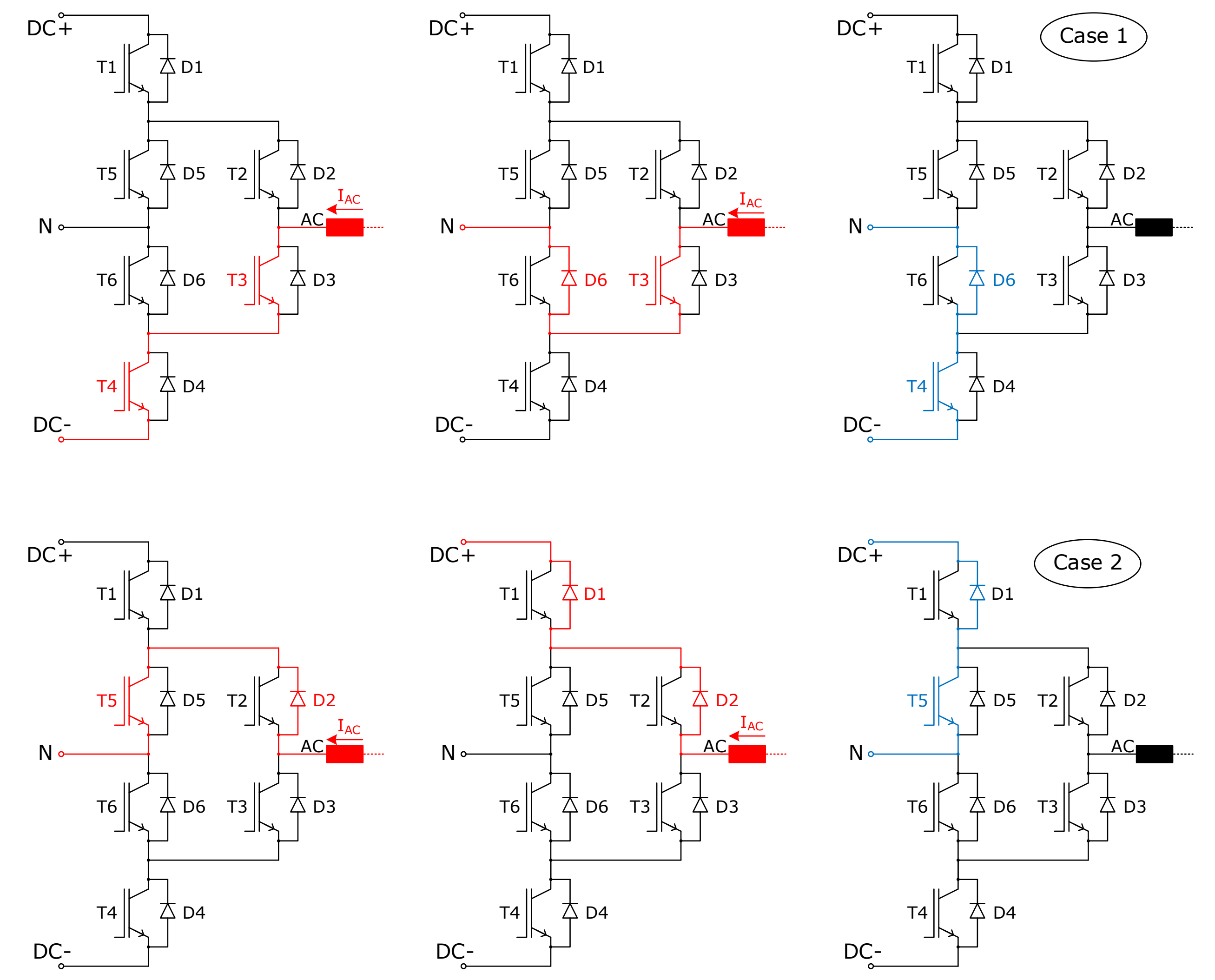
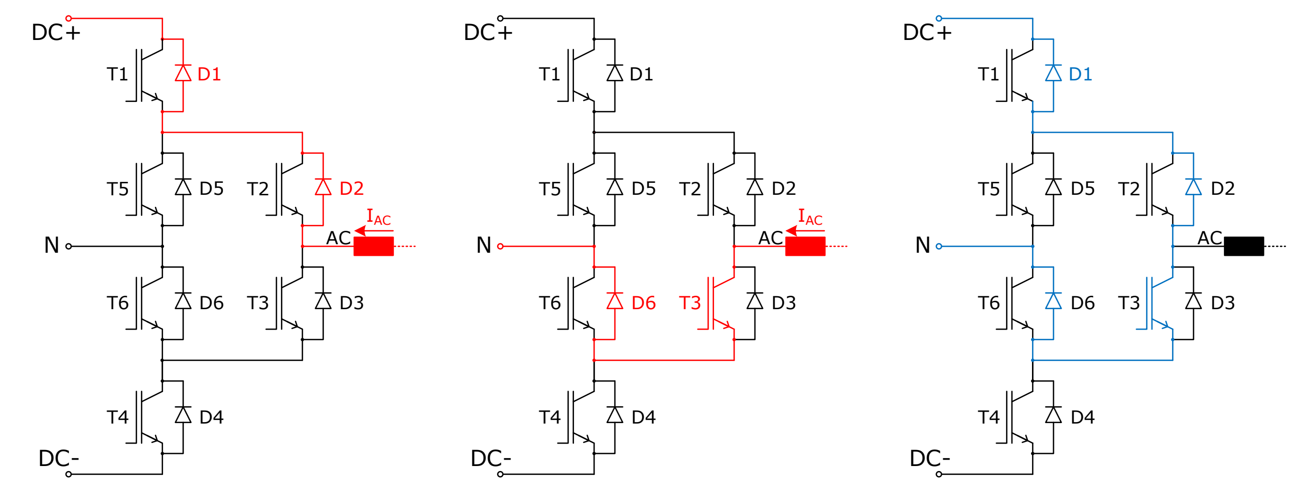


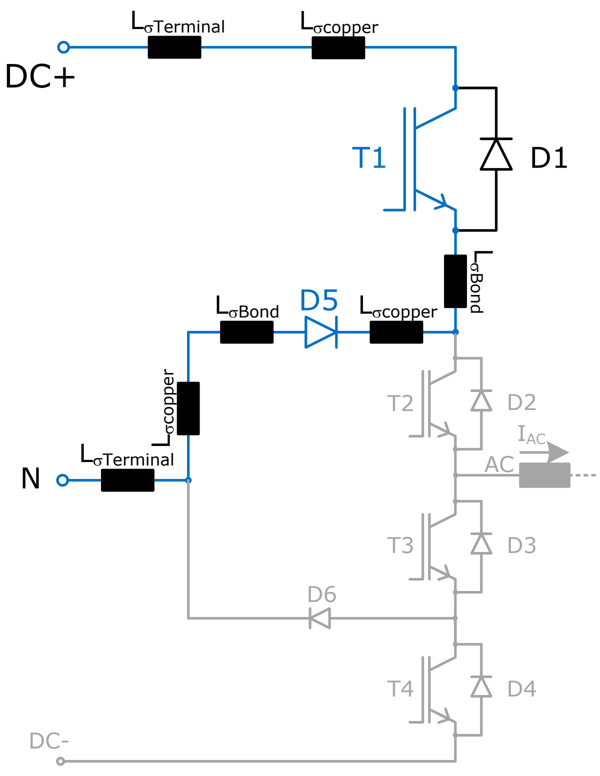
Figure 20: ANPC LF/HF current paths (red) and commutation loop (blue) for operating area 4



2.4 Commutation inductance

When a conducting switch is turned off it experiences a voltage overshoot. This overshoot is because the stray inductance in the current path needs to be overcome.
Figure 21 shows exemplarily (NPC short commutation loop, operating area 1) the stray inductances that form the commutation inductance. In addition to the shown stray inductances also a coupling of inductances needs to be concerned. The sum of all stray inductances (and their possible coupling) is called commutation inductance.

Figure 21: NPC commutation inductance (exemplarily)



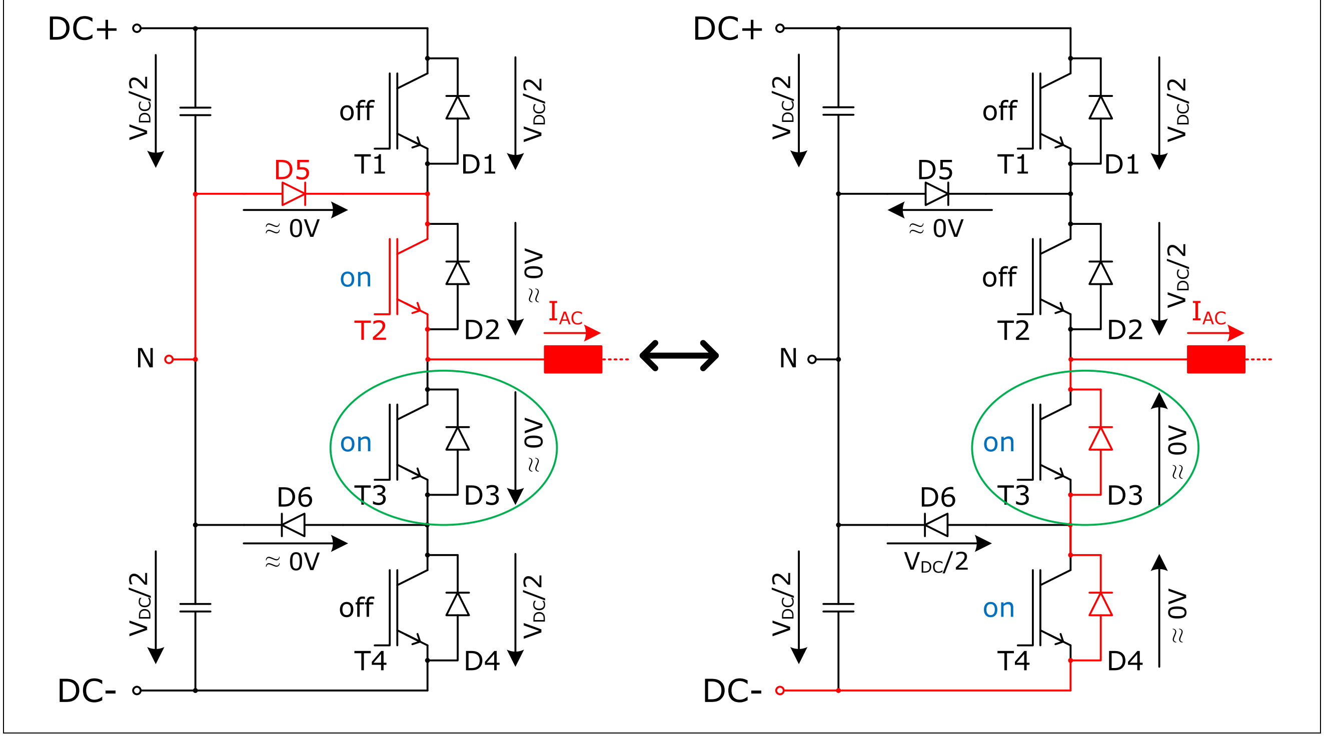
2.5 Semiconductor switching losses

The turn-on or turn-off process of a semiconductor produces losses. Those switching losses are defined by the multiplication of the voltage change across and the current change through the switching device during the switching process.

2.5.1 Switching losses of Diode2 (NPC)

The inner diodes D2 and D3 produce almost no switching losses. Figure 22 shows the two current paths in operating area 2, the voltages across the semiconductors, and the switching states of the IGBTs. In the image on the right the load current flows from DC- across D4 and D3 to the AC terminal. The IGBTs T3 and T4 are turned on. As a current flows the voltages across the diodes correlates to their forward voltage drops. Here it would make no difference whether T3 and T4 were switched on or off.
For changing the current path from what is shown in the right to what is shown in the left image in Figure 22 first IGBT T4 is turned off and then IGBT T2 is turned on. As the driving voltage from N to AC is larger than that from DC- to AC the current commutates to the upper path.
As stated above the switching losses are calculated by multiplying the voltage change across and the current change through the particular device. In operating area 2 IGBT T3 stays switched on all the time no matter whether the antiparallel diode is conducting current or not. During diode D3 conduction the voltage drop is almost zero. When D3 is not conducting the voltage across it is kept almost zero by the always turned-on IGBT T3. Here “close to zero” refers to the forward voltage drop of IGBT T3.
As the voltage change across D3 is close zero (it is the difference between the forward voltage drops of IGBT and diode) the losses are also close zero and hence negligible.

Figure 22: Switching losses of D3 (NPC) in operating area 2



The same methodology as explained for D3 (operating area 2) also applies for the switching losses of diode D2 in operating area 3.

3. Semikron Danfoss 3L Datasheets

Concerning the content Semikron Danfoss 2L and 3L datasheets are very much alike. An explanation of the particular values is given in Semikron Danfoss’ “Application Manual Power Semiconductors” [2]. The differences can be found in the stray inductances of the devices and the switching losses of certain semiconductors as described below.

3.1 Measurements

The datasheet values for switching losses and stray inductances are measured in the abovementioned commutations. That guarantees values that meet the real switching behaviour as long as the PWM pattern is generated by using the sine-triangular comparison.
Please note that if different PWM patterns (different from what the sine-triangular comparison delivers) are used the Semikron Danfoss datasheet values may not thoroughly apply any longer.
Of course, other PWM patterns are allowed, but it remains with the user to specify valid datasheet values.

3.2 Measurement of commutation inductances

The commutation inductances are measured by using a setup with an additional external switch and an external diode where required.
The following figures show the measurement setups of NPC (Figure 23 and Figure 24), TNPC (Figure 25, Figure 26 and Figure 27), and ANPC (Figure 28 and Figure 29): the external switch (and diode) as well as a load inductor are drawn in green colour, blue marks the involved semiconductors, the other semiconductors are marked grey.
The external switch pulses twice: During the first pulse, the load inductor is charged. When the external switch turns off the load current commutates to the commutation loop, which is under investigation (drawn in blue colour). At turn-on of the second pulse, the current commutates back to the external switch and hence the commutation path is turned off. This turn-off is the time when the voltage across and the di/dt through the commutation loop is measured. From these values, the commutation inductance can be calculated.
This method for measuring the commutation inductances is as close to IEC60747 as possible. The standard states that only external semiconductors may be used for switching and the di/dt is measured when the module's internal diodes turn-off the load current. The measurement of the 2L commutation inductance in TMLI (Figure 27) follows this standard to the letter.
For the measurements of the 3L commutation inductances, some slight modifications need to be made: when the load current is turned off a current path is needed. As the 3L commutation paths do not only include diodes but also one or more IGBTs. Those IGBTs need to be involved in that measurement. During the measurement, they are permanently turned on and provide the required current path.

Figure 23 and Figure 24 show how the NPC commutation inductances of the two short and the two long commutation loops are measured. As the module layouts are very symmetrical the two short (as well as the two long) commutation loops are very similar and hence show the same commutation inductance in regard of measurement accuracy. For that reason, the datasheets contain one value for the short (L_{sCE1}) and one for the long (L_{sCE2}) commutation loop.

Figure 25 and Figure 26 show the setups for the measurement of the TNPC commutation inductances. These paths differ slightly from the commutation loops shown in Figure 5 to Figure 8 because in order to achieve a current path that can be turned on and off by an external switch it is necessary to use for example D1 instead of T1 (which would be involved in the real commutation loop). This deviation of the current path leads to a deviation of the measured value. As T1 and D1 are located very close to each other this deviation is minimal and may be neglected.

Semikron Danfoss TNPC modules are designed with a very symmetrical layout; as consequence all four measurement setups lead to the same commutation inductance (within the boundaries of measurement accuracy). This is why the datasheets come with only one value for the 3L commutation inductance (L_{sCE1}).

Under certain circumstances, it is possible to operate a 3L TNPC module in 2L mode, which means that IGBTs T2 and T3 are inactive and only T1 and T4 (and their inverse diodes D1 and D4) are operated. For a better estimation of the before mentioned circumstances Semikron Danfoss decided to measure the 2L commutation inductance and place it in the datasheet as well. This value is called L_{CE} in accordance with the stray inductance given in Semikron Danfoss 2L module datasheets.

Figure 28 and Figure 29 show how the ANPC commutation inductances of the four short and the two long commutation loops are measured. As the module layouts are very symmetrical the four short (as well as the two long) commutation loops are very similar and hence show the same commutation inductance in regard of measurement accuracy. For that reason, the datasheets contain one value for the short (L_{sCE1}) and one for the long (L_{sCE2}) commutation loop.

Figure 23: Measurement setup of NPC commutation inductances in operating areas 1 (left) and 2 (right)

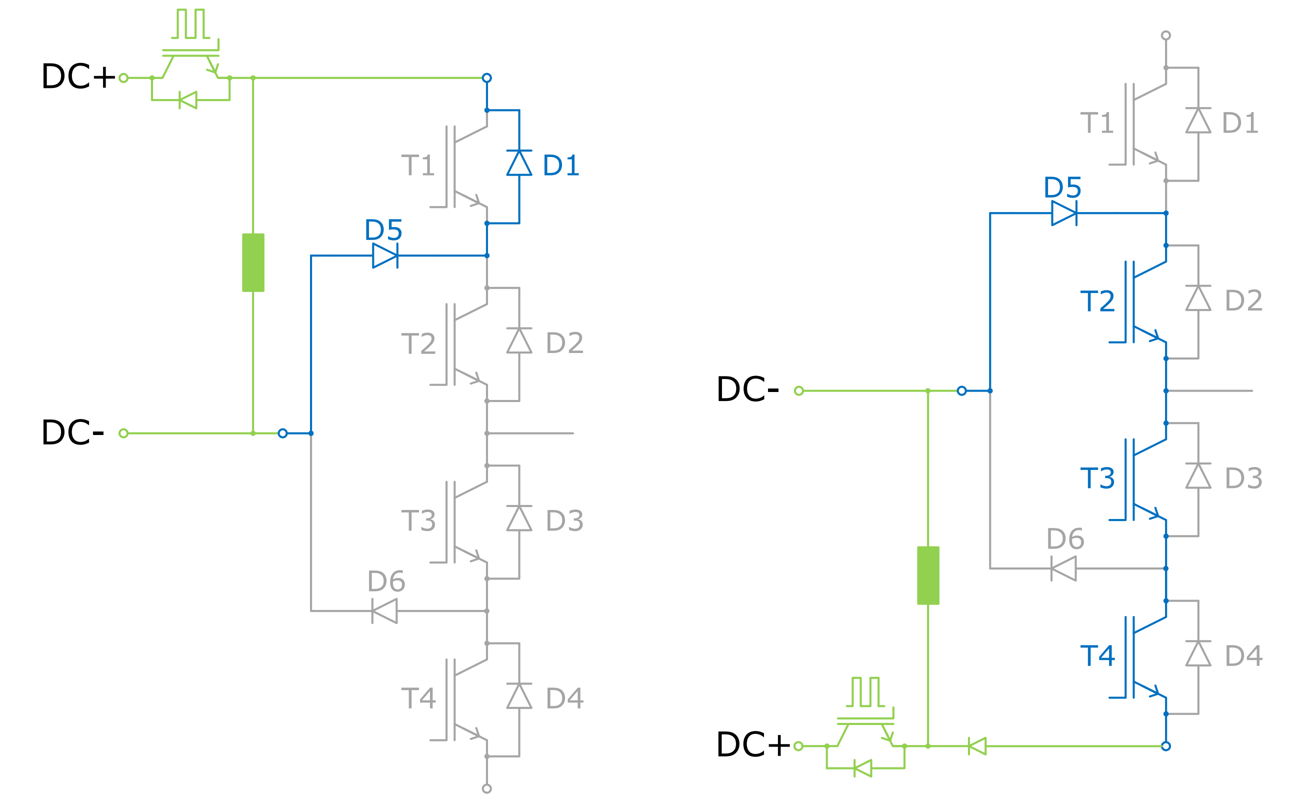


Figure 24: Measurement setup of NPC commutation inductances in operating areas 3 (left) and 4 (right)

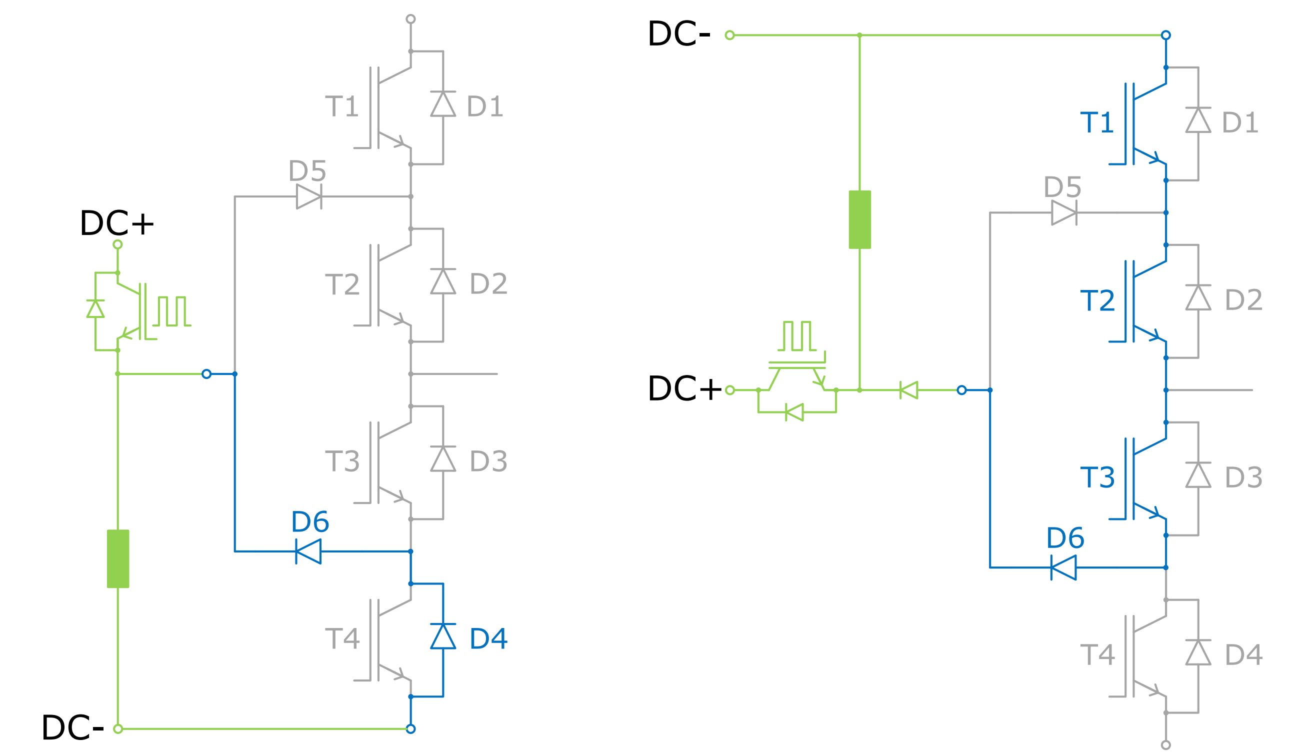


Figure 25: Measurement setup of TNPC commutation inductances in upper module half

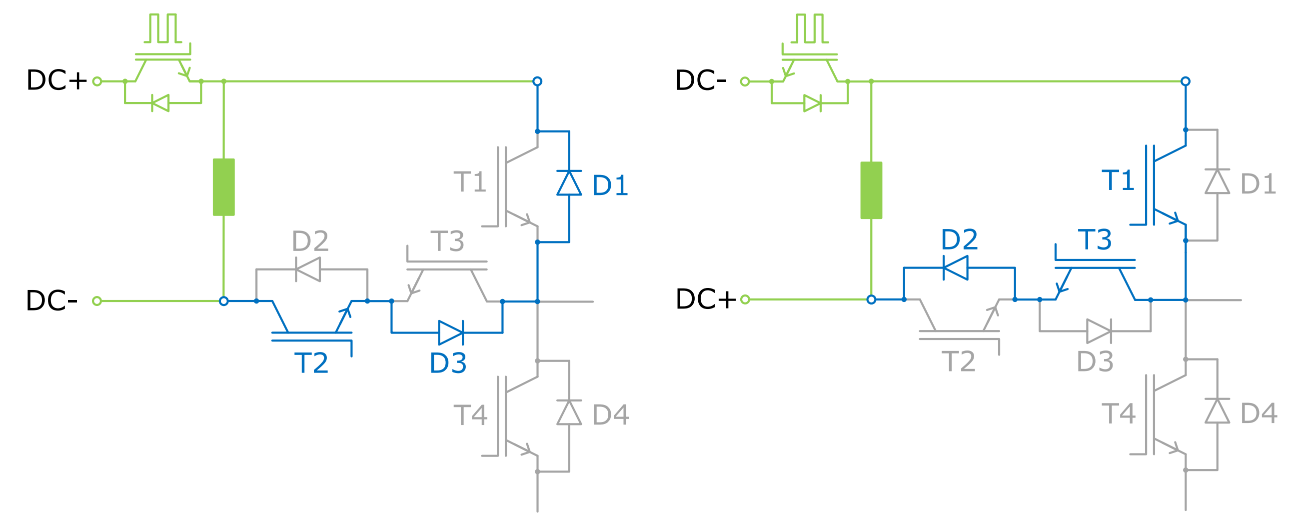


Figure 26: Measurement setup of TNPC commutation inductances in lower module half

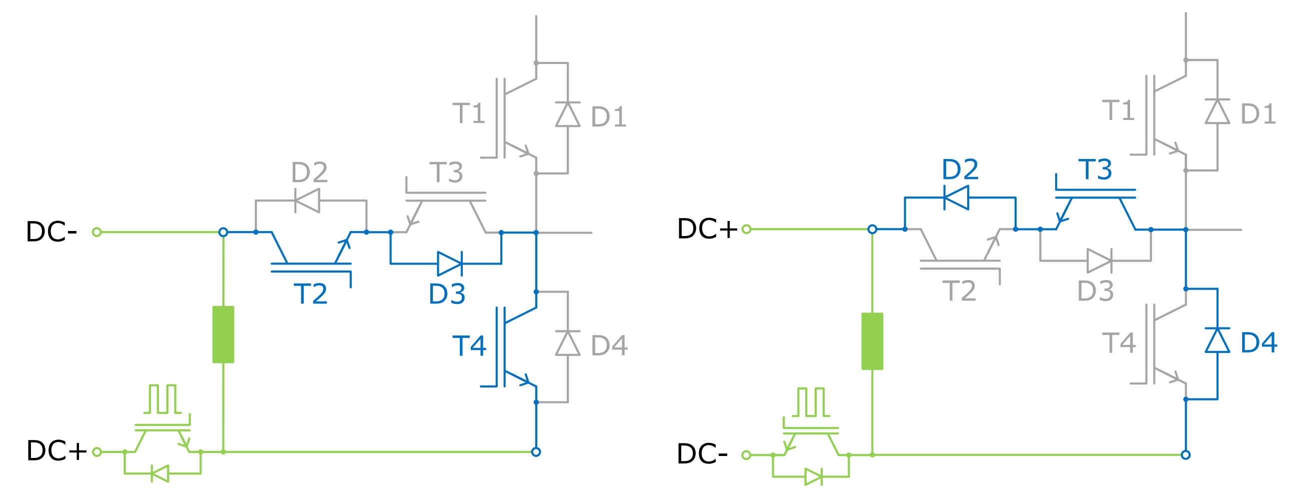


Figure 27: Measurement setup of 2L commutation in TNPC

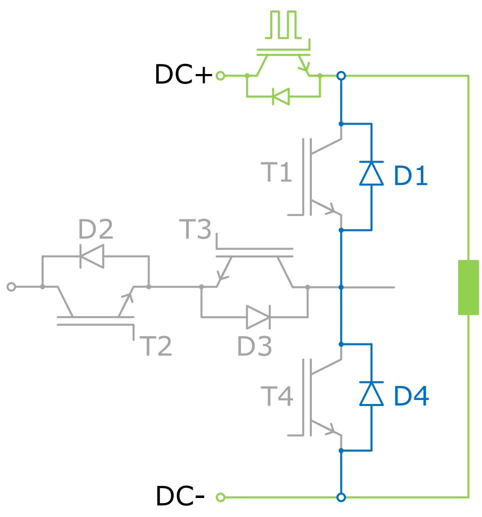


Figure 28: Measurement setup of ANPC commutation inductances in operating areas 1 and 4 (left) and 2 and 3 (right)

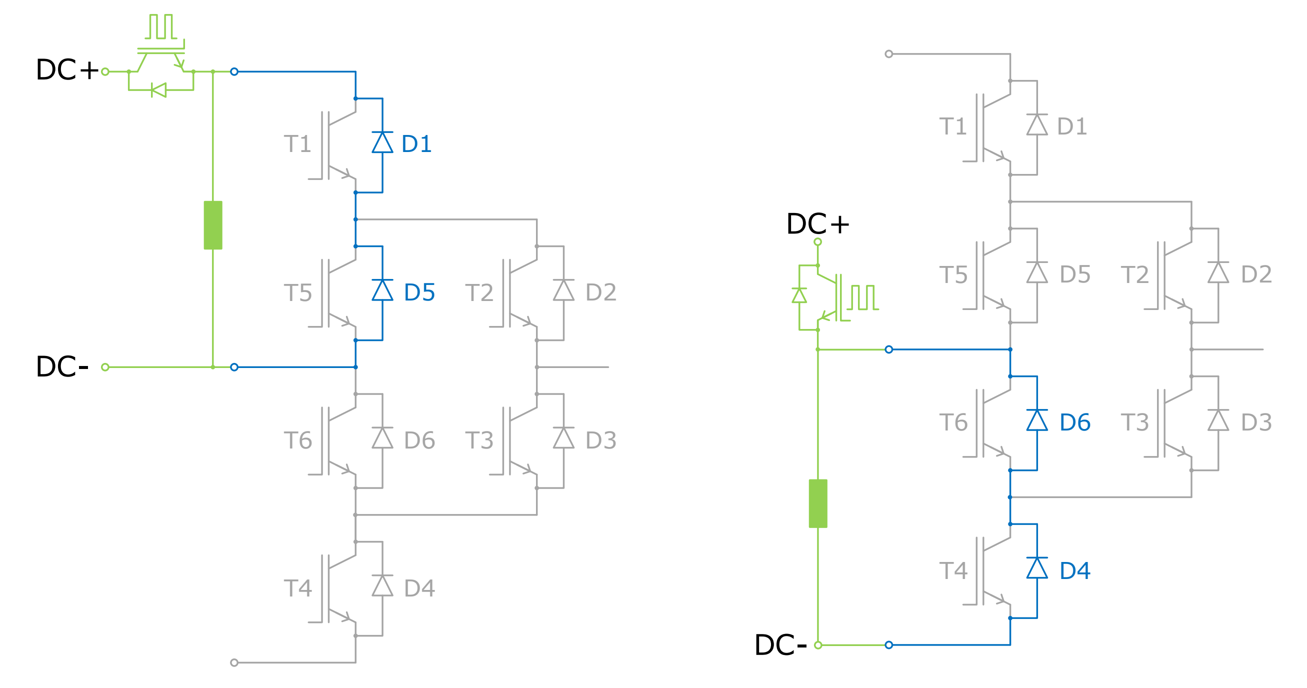
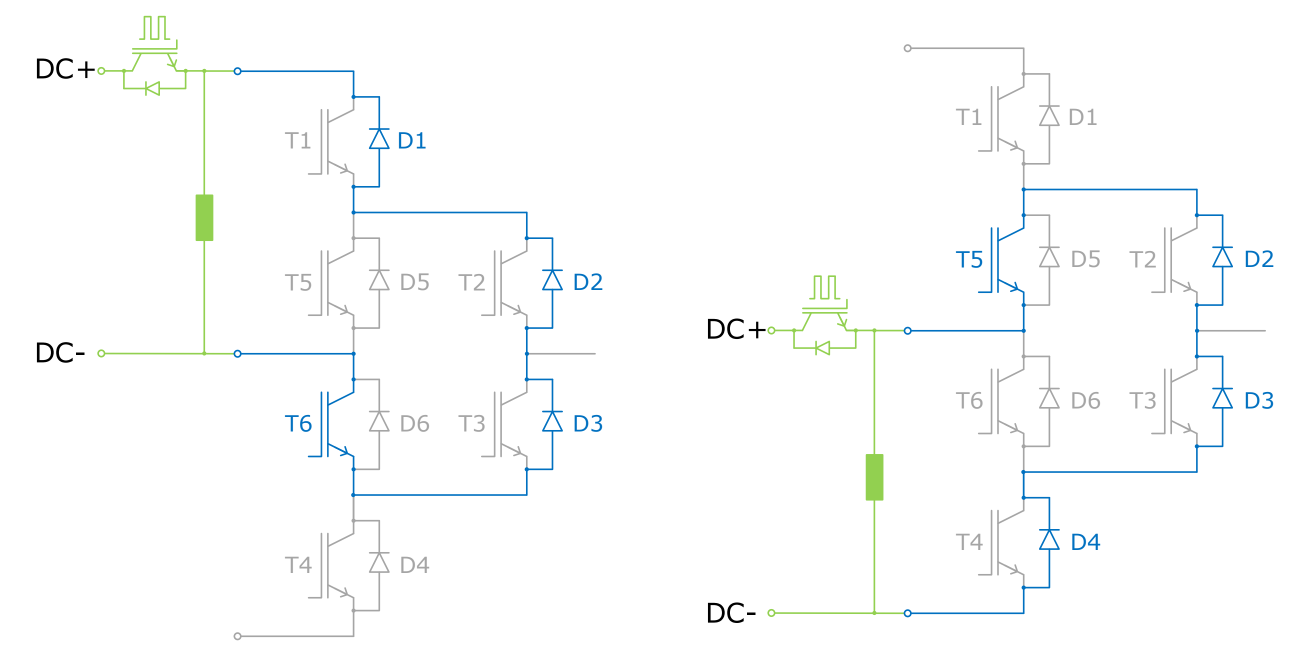


Figure 29: Measurement setup of ANPC commutation inductances transition from operating areas 1 to operating are 2 (left) and operating are 3 to operating are 4 (right)



3.3 Diode2 switching losses

As explained in chapter 2.5.1 the switching losses E_{rr} of the inner diodes D2 and D3 (in the datasheets referred to as "Diode2") are almost zero, hence, Diode2 will not be a restricting element in a Semikron Danfoss NPC module concerning junction temperature. For that reason the almost not existing losses are not measured and the column for Diode2 switching losses contains a dash ("-").

3.4 List of datasheet figures

Semikron Danfoss 3L datasheets offer space for up to 24 diagrams. Depending on the status of the datasheet (e.g. “target” or “final”) it is possible that less diagrams are shown. In that case, the numbering of the possible diagram subtitles (shown in Table 1, Table 2, and Table 3) remains the same. Example: When Fig. 11 and Fig. 12 are missing, Fig. 10 is directly followed by Fig. 13 and all further figures move up.
The figure numbering of NPC, TNPC, and ANPC is similar where possible. Example: Fig. 3 (NPC) shows the switching losses of IGBT1 and Diode5, Fig. 3 (TNPC) shows these values of IGBT1 and Diode2, Fig. 3 (ANPC) those of IGBT1 and Diode1. In all three topologies, the load current is commutated between the two mentioned semiconductors. The same methodology applies for all figures.
Fig. 2 and Fig. 14 display a rated current as a function of temperature: for modules with baseplate (e.g. SEMiX) this is the case temperature (T_C). For modules without baseplate (e.g. MiniSKiiP) it is the heatsink temperature (T_S).

3.4.1 MLI datasheet figures

Table 1: Figure captions in Semikron Danfoss 3-Level NPC datasheets	
Fig. 1	Typ. IGBT1 output characteristic
Fig. 2	IGBT1 rated current vs. Temperature I_C=f(T_C) [or I_C=f(T_s), depending on module type]
Fig. 3	Typ. IGBT1 & Diode5 turn-on/-off energy =f(I_C)
Fig. 4	Typ. IGBT1 & Diode5 Turn-on/-off energy = f(R_G)
Fig. 5	Typ. IGBT1 transfer characteristic
Fig. 6	Typ. IGBT1 gate charge characteristic
Fig. 7	Typ. IGBT1 switching times vs. I_C
Fig. 8	Typ. IGBT1 switching times vs. gate resistor R_G
Fig. 9	Transient thermal impedance of IGBT1 & Diode5
Fig. 10	Diode5 forward characteristic
Fig. 11	Typ. Diode5 peak reverse recovery current
Fig. 12	Typ. Diode5 recovery charge
Fig. 13	Typ. IGBT2 output characteristic
Fig. 14	IGBT2 rated current vs. Temperature I_C=f(T_C) [or I_C=f(T_s), depending on module type]
Fig. 15	Typ. IGBT2 & Diode1 turn-on/-off energy =f(I_C)
Fig. 16	Typ. IGBT2 & Diode1 Turn-on/-off energy = f(R_G)
Fig. 17	Typ. IGBT2 transfer characteristic
Fig. 18	Typ. IGBT2 gate charge characteristic
Fig. 19	Typ. IGBT2 switching times vs. I_C
Fig. 20	Typ. IGBT2 switching times vs. gate resistor R_G
Fig. 21	Transient thermal impedance of IGBT2, Diode1 & Diode2
Fig. 22	Diode1 & Diode2 forward characteristic
Fig. 23	Typ. Diode1 peak reverse recovery current
Fig. 24	Typ. Diode1 recovery charge

3.4.2 TMLI datasheet figures

Table 2: Figure captions in Semikron Danfoss 3-Level TNPC datasheets	
Fig. 1	Typ. IGBT1 output characteristic
Fig. 2	IGBT1 rated current vs. Temperature I_C=f(T_C) [or I_C=f(T_s), depending on module type]
Fig. 3	Typ. IGBT1 & Diode2 turn-on/-off energy =f(I_C)
Fig. 4	Typ. IGBT1 & Diode2 Turn-on/-off energy = f(R_G)
Fig. 5	Typ. IGBT1 transfer characteristic
Fig. 6	Typ. IGBT1 gate charge characteristic
Fig. 7	Typ. IGBT1 switching times vs. I_C
Fig. 8	Typ. IGBT1 switching times vs. gate resistor R_G
Fig. 9	Transient thermal impedance of IGBT1 & Diode2
Fig. 10	Diode5 forward characteristic
Fig. 11	Typ. Diode2 peak reverse recovery current
Fig. 12	Typ. Diode2 recovery charge
Fig. 13	Typ. IGBT2 output characteristic
Fig. 14	IGBT2 rated current vs. Temperature I_C=f(T_C) [or I_C=f(T_s), depending on module type]
Fig. 15	Typ. IGBT2 & Diode1 turn-on/-off energy =f(I_C)
Fig. 16	Typ. IGBT2 & Diode1 Turn-on/-off energy = f(R_G)
Fig. 17	Typ. IGBT2 transfer characteristic
Fig. 18	Typ. IGBT2 gate charge characteristic
Fig. 19	Typ. IGBT2 switching times vs. I_C
Fig. 20	Typ. IGBT2 switching times vs. gate resistor R_G
Fig. 21	Transient thermal impedance of IGBT2, Diode1
Fig. 22	Diode1 forward characteristic
Fig. 23	Typ. Diode1 peak reverse recovery current
Fig. 24	Typ. Diode1 recovery charge

AMLI datasheet figures

Table 3: Figure captions in Semikron Danfoss 3-Level ANPC datasheets	
Fig. 1	Typ. IGBT1 output characteristic
Fig. 2	IGBT1 rated current vs. Temperature I_C=f(T_C) [or I_C=f(T_s), depending on module type]
Fig. 3	Typ. IGBT1 & Diode1 turn-on/-off energy =f(I_C)
Fig. 4	Typ. IGBT1 & Diode1 Turn-on/-off energy = f(R_G)
Fig. 5	Typ. IGBT1 transfer characteristic
Fig. 6	Typ. IGBT1 gate charge characteristic
Fig. 7	Typ. IGBT1 switching times vs. I_C
Fig. 8	Typ. IGBT1 switching times vs. gate resistor R_G
Fig. 9	Transient thermal impedance of IGBT1 & Diode1
Fig. 10	Diode1 forward characteristic
Fig. 11	Typ. Diode1 peak reverse recovery current
Fig. 12	Typ. Diode1 recovery charge
Fig. 13	Typ. IGBT2 output characteristic
Fig. 14	IGBT2 rated current vs. Temperature I_C=f(T_C) [or I_C=f(T_s), depending on module type]
Fig. 15	Typ. IGBT2 & Diode2 turn-on/-off energy =f(I_C)
Fig. 16	Typ. IGBT2 & Diode2 Turn-on/-off energy = f(R_G)
Fig. 17	Typ. IGBT2 transfer characteristic
Fig. 18	Typ. IGBT2 gate charge characteristic
Fig. 19	Typ. IGBT2 switching times vs. I_C
Fig. 20	Typ. IGBT2 switching times vs. gate resistor R_G
Fig. 21	Transient thermal impedance of IGBT2, Diode2
Fig. 22	Diode2 forward characteristic
Fig. 23	Typ. Diode2 peak reverse recovery current
Fig. 24	Typ. Diode2 recovery charge

Figure 1: NPC current paths (red) and commutation loop (blue) for operating area 1 3
Figure 2: NPC current paths (red) and commutation loop (blue) for operating area 3 3
Figure 3: NPC current paths (red) and commutation loop (blue) for operating area 2 4
Figure 4: NPC current paths (red) and commutation loop (blue) for operating area 4 4
Figure 5: TNPC current paths (red) and commutation loop (blue) for operating area 1 5
Figure 6: TNPC current paths (red) and commutation loop (blue) for operating area 3 5
Figure 7: TNPC current paths (red) and commutation loop (blue) for operating area 2 5
Figure 8: TNPC current paths (red) and commutation loop (blue) for operating area 4 6
Figure 9: ANPC HF/LF current paths (red) and commutation loop (blue) for operating area 1 6
Figure 10: ANPC HF/LF current paths (red) and commutation loops (blue) for transitions from operating area 1 to operating area 2 7
Figure 11: ANPC HF/LF current paths (red) and commutation loop (blue) for operating area 2 7
Figure 12: ANPC HF/LF current paths (red) and commutation loop (blue) for operating area 3 8
Figure 13: ANPC HF/LF current paths (red) and commutation loops (blue) for transitions from operating area 3 to operating area 4 8
Figure 14: ANPC HF/LF current paths (red) and commutation loop (blue) for operating area 4 9
Figure 15: ANPC LF/HF current paths (red) and commutation loop (blue) for operating area 1 9
Figure 16: ANPC LF/HF current paths (red) and commutation loops (blue) for transitions from operating area 1 to operating area 2 10
Figure 17: ANPC LF/HF current paths (red) and commutation loop (blue) for operating area 2 10
Figure 18: ANPC LF/HF current paths (red) and commutation loop (blue) for operating area 3 11
Figure 19: ANPC LF/HF current paths (red) and commutation loops (blue) for transitions from operating area 3 to operating area 4 11
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Table 1: Figure captions in Semikron Danfoss 3-Level NPC datasheets 19
Table 2: Figure captions in Semikron Danfoss 3-Level TNPC datasheets......................................20
Table 3: Figure captions in Semikron Danfoss 3-Level ANPC datasheets 21

Symbols and Terms

Letter Symbol	Term
2L	Two level
3L	Three level
AC	Alternating current
AMLI	ANPC-type Multi Level Inverter
ANPC	Active Neutral Point Clamped
DC-	Negative potential (terminal) od a direct voltage source
DC+	Positive potential (terminal) of a direct voltage source
di/dt	Change of current per time
Err	Energy dissipation during reverse recovery (diode)
I_{AC}	RMS output current of a device
I_C	Continuous collector current
IGBT	Insulated Gate Bipolar Transistor
L_{CE}	Parasitic collector-emitter inductance
L_{sCE1}	Parasitic 3L commutation inductance short path
L_{sCE2}	Parasitic 3L commutation inductance long path
MLI	Multi Level Inverter
N	Neutral potential (terminal) of a direct voltage source; midpoint between DC+ and DC-
NPC	Neutral Point Clamped
PWM	Pulse Width Modulation
R_G	Gate circuit resistance
RMS	Root Mean Square
T_C	Case temperature
TMLI	T-type Multi Level Inverter
TNPC	T-type Neutral point Clamped
T_S	Heatsink temperature

A detailed explanation of the terms and symbols can be found in the "Application Manual Power Semiconductors" [2].

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IMPORTANT INFORMATION AND WARNINGS

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