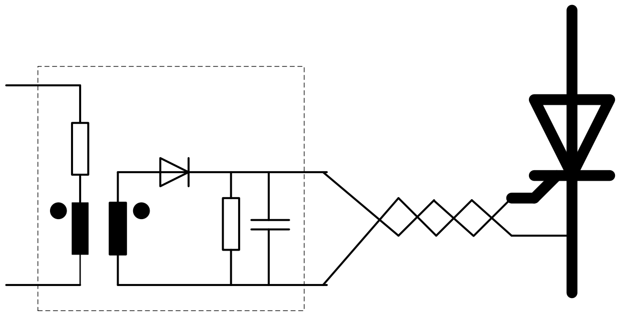
Infineon Technologies Bipolar

Triggering Electrically Triggered Thyristors (ETTs)



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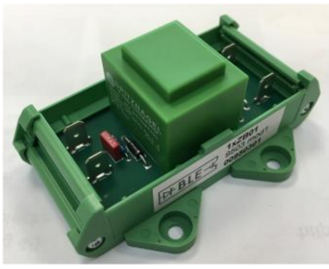

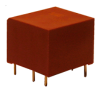

Abstract

Triggering Electrically Triggered Thyristors (ETTs)

There is a long history in triggering bipolar semiconductors like thyristors. After decades of development, the thyristors are no longer comparable with the very early products from the 1960s. The products were improved for all-important parameters like voltage and current. This paper describes how to trigger modern standard and high-power, high-voltage thyristors and gives an overview about application requirements. General information is described in AN 2012-01. Triggering light-triggered thyristors is described in AN 2018-07.

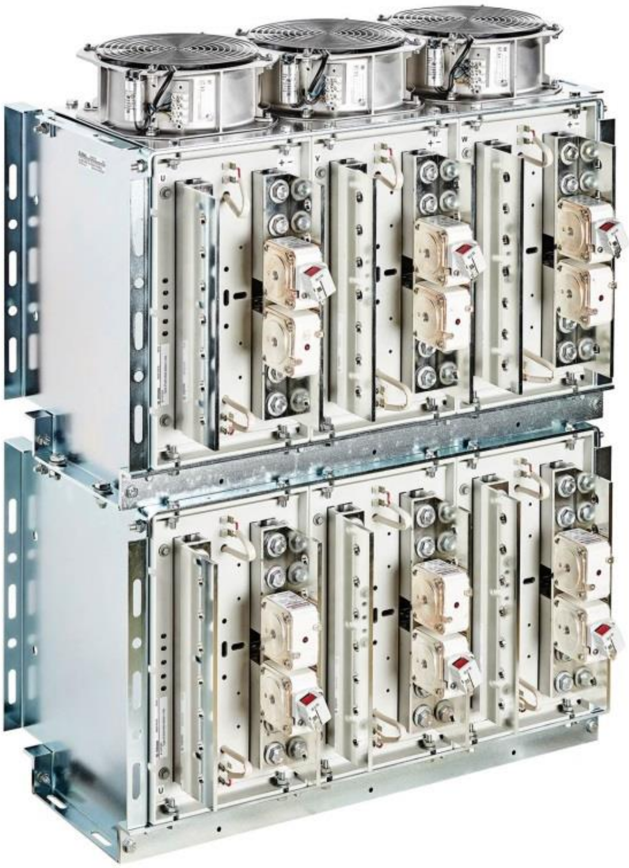

Figure 1. (B6C)A(B6C) Rectifier

Document history

Action	Remark	Name	Date
Created		JS	20180822
V5	Explanation for B6C control concept added	JS	20181217
V6	Final	JS	20190312
V6c	Corrections	JS	20190828
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Contents

1 Triggering electrically triggered thyristors (ETTs)

There is a long history in triggering bipolar semiconductors like thyristors. After decades of development, the thyristors are no longer comparable with the very early products from the 1960's. The products were improved for all-important parameters like voltage and current. This paper describes how to trigger modern standard and high-power, high-voltage thyristors and gives an overview about application requirements. General information is described in AN 2012-01. Triggering light triggered thyristors is described in AN 2018-07.

2 Thyristor gate technologies

Proper triggering depends on the gate technology of the chosen thyristor. Infineon offers two gate structure technologies depending on the thyristor technology, the standard gate and the improved amplifying gate structure.

2.1 Standard gate

Historically, all thyristors were equipped with a standard gate. Turning on the thyristor requires well-defined triggering pulses with high di/dt, high source voltage and high gate current. Nowadays such gates exist only for thyristor pellets < 31 mm in diameter. Those pellets can be found usually in Power Blocks up to 50 mm and in Discs ≤ 48 mm in diameter. These thyristors are more critical regarding weak gate current or soft firing because the trigger unit must deliver all the required trigger energy.

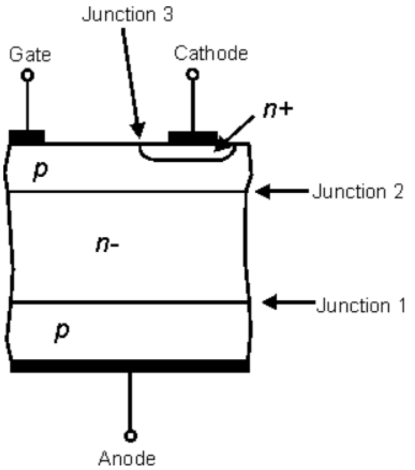


Figure 2. Physical gate structure of a thyristor with standard gate

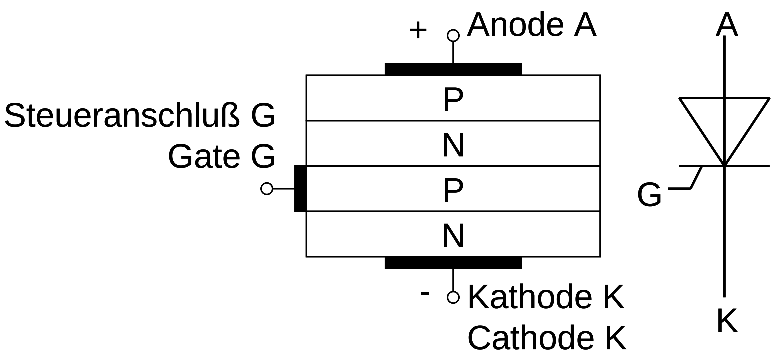


Figure 3. Vertical schematic of a thyristor with standard gate. Equivalent circuit

2.2 Amplifying gate

Triggering of large electrically triggered thyristors (ETT) requires a high power gate pulse. To lower the trigger effort modern large thyristors are equipped with cascaded auxiliary thyristors at the inner gate (Figure 4). These thyristors with an amplifying gate are much more robust regarding weak gate current because the main trigger energy will be generated from the anode voltage by the gate current amplifiers. Only the first (small) amplifying thyristors needs to be triggered safely. The requirements to the trigger signal are given by the first auxiliary thyristor. During early turn on (1-2µs), the first auxiliary thyristor is exposed to the di/dt of the main circuit. Further amplifying thyristors (if there are any) and the main thyristor will be turned on according to the thyristor design in the right manner independent from the external gate current.

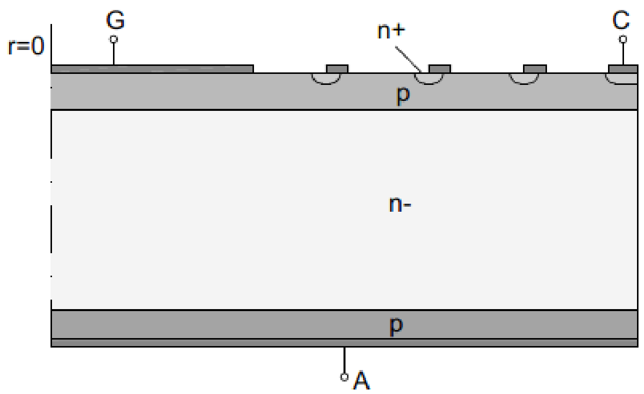


Figure 4. Physical gate structure of a thyristor with amplifying gate (three amplifying auxiliary thyristors)

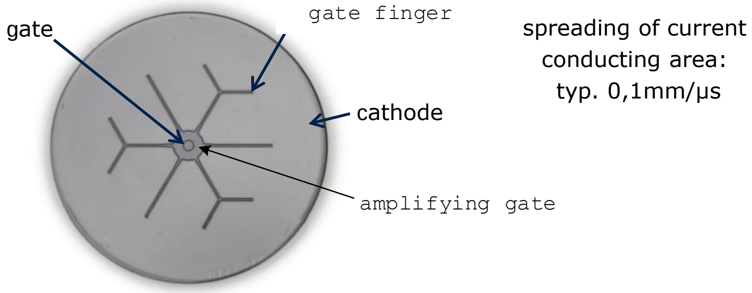


Figure 5. Cathode side view on a thyristor with amplifying gate (one amplifying auxiliary thyristor)

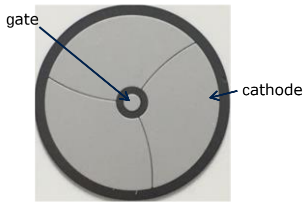


Figure 6. Cathode side view on a thyristor with standard gate

2.3 Gate cathode voltage demand

The higher the di/dt of the anode current, the higher the voltage drop on the internal gate resistor R_G (see Figure 7). The gate driver must be able to overdrive that voltage drop. Otherwise the auxiliary thyristor cannot be triggered properly (soft firing) (see Table 3 and Table 7).

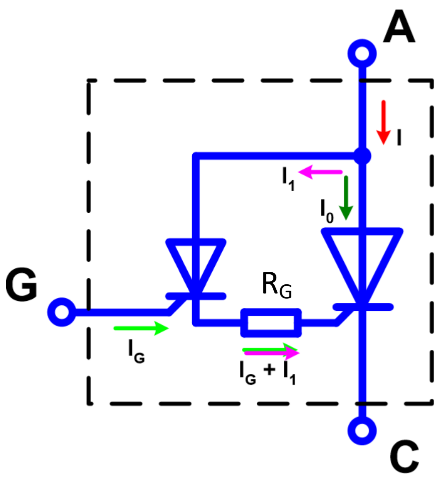


Figure 7. Triggering of a thyristor with amplifying gate. Simplified equivalent circuit

2.4 Conclusion for modern thyristors in applications

The features of modern thyristors lead to several advantages for the system design. Keep in mind, that the thyristor is still an analogous component with temperature dependent characteristics. Triggering at low temperatures is more critical (e.g. -40 °C). The triggering must work safely over the whole planned operating temperature area.

Design feature	Advantage	Customer benefit
Fingered gate	Increased di/dt capability	More robust system design
Amplifying gate	Less trigger power	Smaller, cheaper trigger circuits
	More trigger energy storage time	Smaller, cheaper trigger circuits
	More immune to soft firing	More reliable operation
	More increased di/dt capability	More robust system design
	More trigger robustness	Trigger circuit design less critical
Shorting	Increased dv/dt capability	More robust system design
Conditional avalanche behavior	Robust against Vrrm overvoltage	More reliable operation

Table 1. Design features of modern thyristors

3 General requirements for triggering ETT's

3.1 Trigger data

The trigger characteristics are given in the data sheet. The designations and abbreviations are explained in detail in AN2012-01 [1].

Zündstrom gate trigger current	T_{vj} = 25 °C, v_D = 12V	I_{GT}	max.	250	mA
Zündspannung gate trigger voltage	T_{vj} = 25 °C, v_D = 12V	V_{GT}	max.	2	V
Nicht zündender Steuerstrom gate non-trigger current	$T_{vj} = T_{vj\,max}$, v_D = 12V $T_{vj} = T_{vj\,max}$, $v_D = 0{,}5\ V_{DRM}$	I_{GD}	max. max.	10 5	mA mA
Nicht zündende Steuerspannung gate non-trigger voltage	$T_{vj} = T_{vj\,max}$, $v_D = 0{,}5\ V_{DRM}$	V_{GD}	max.	0,2	V
Haltestrom holding current	T_{vj} = 25°C, v_D = 12V	I_H	max.	500	mA
Einraststrom latching current	T_{vj} = 25°C, v_D = 12V, $R_{GK} \geq 10\ \Omega$ i_{GM} = 1 A, di_G/dt = 1 A/µs, t_g = 20 µs	I_L	max.	2500	mA
Vorwärts- und Rückwärts-Sperrstrom forward off-state and reverse current	$T_{vj} = T_{vj\,max}$ $v_D = V_{DRM}$, $v_R = V_{RRM}$	i_D, i_R	max.	150	mA
Zündverzug gate controlled delay time	DIN IEC 60747-6 T_{vj} = 25 °C, i_{GM} = 1 A, di_G/dt = 1 A/µs	t_{gd}	max.	4	µs

Table 2. Trigger data for T1500N, an example.

The data describe the semiconductors characteristics. The real trigger signal needs to be designed according the application needs. Therefore, further parameters need to be considered. See also [1]

Abbreviation	Designation	Recommended value	Comment
I_{GT}	Gate trigger current	0.12 – 0.35 A	Range for the major thyristor portfolio. According to datasheet of the applied thyristor. Basis for further gate current design. Above this value each thyristor of a given type will trigger
I_{GD}			Typical value. Below this value no thyristor will trigger
di_G/dt	Gate current slew rate	1-6 A/µs (In 0.5 to 1 µs to i_{GM})	Range for the major thyristor portfolio. According to datasheet of the applied thyristor
i_{GM}	Peak gate current	8 to 10*I_{GT} up to 3.5 A	Depends on the thyristor type
i_{G_roof}	Roof gate current	2 to 4* I_{GT} up to 1.4 A	Depends on the thyristor type
t_G	Duration of the trigger pulse	30-100 µs	Depends on current rise time in load circuit

V_L	Open circuit voltage of the control circuit	>30 V for pellets <30 mm >12 V for pellets >=30 mm	Pellets < 30 mm are usually equipped with standard gate. See 2.1
t_{G_min}	Absolute minimum gate trigger pulse duration	10 µs	Shorter pulses are not allowed, thyristor will not turn on completely and may be damaged.
t_{gd}	Gate controlled delay time	2 to 4 µs	According to datasheet of the applied thyristor. See also Figure 11.
t_{iGM}	Absolute minimum time for gate current peak	2 to 4 µs	Like Gate controlled delay time of the applied thyristor. See also t_{gd}

Table 3. Recommended trigger data for applications

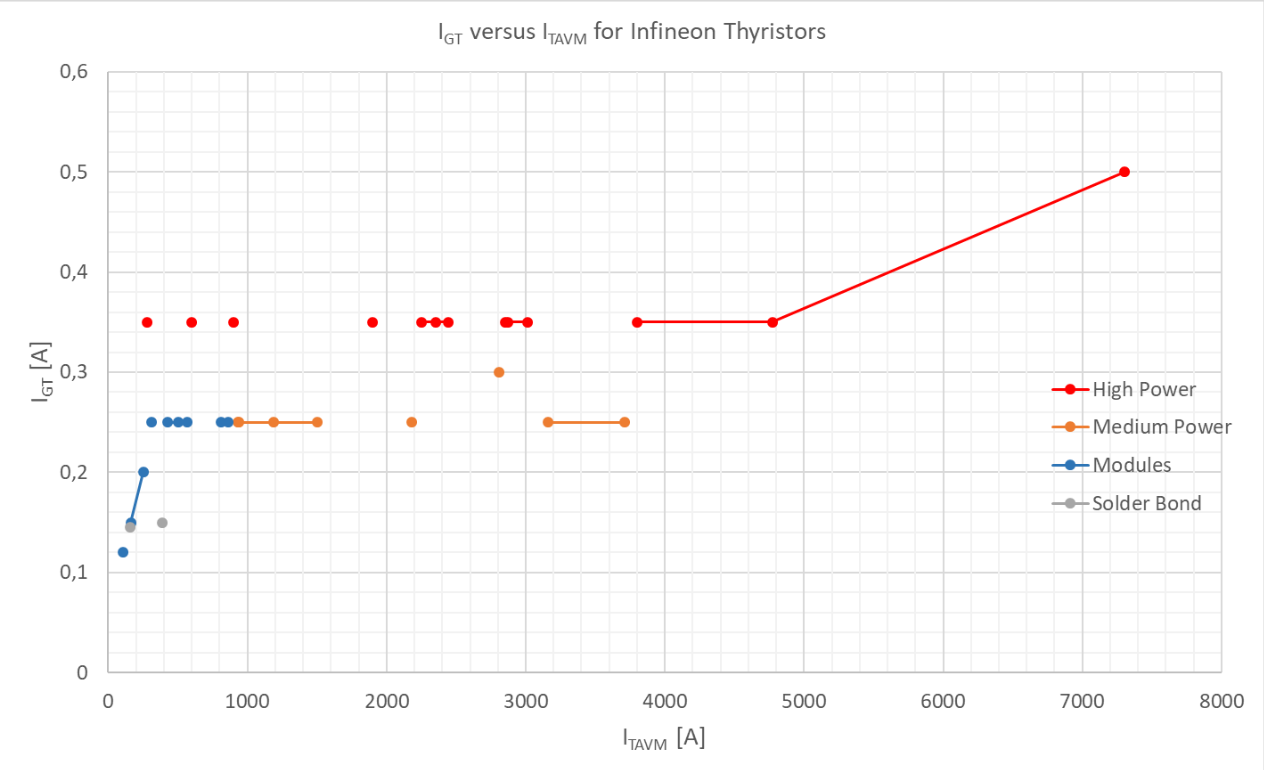


Figure 8. I_{GT} versus I_{TAVM} for the Infineon thyristor portfolio

3.2 Limitations

The thyristor is not allowed to be triggered during reverse operation. Under that condition, the gate current may increase to higher values without control. That leads to unplanned gate power dissipation. See chapter 3.3. In addition, the blocking losses will increase and therefore the overall converter losses will increase.

3.3 Static gate characteristics

The static gate characteristics for each individual thyristor are given in the data sheet.

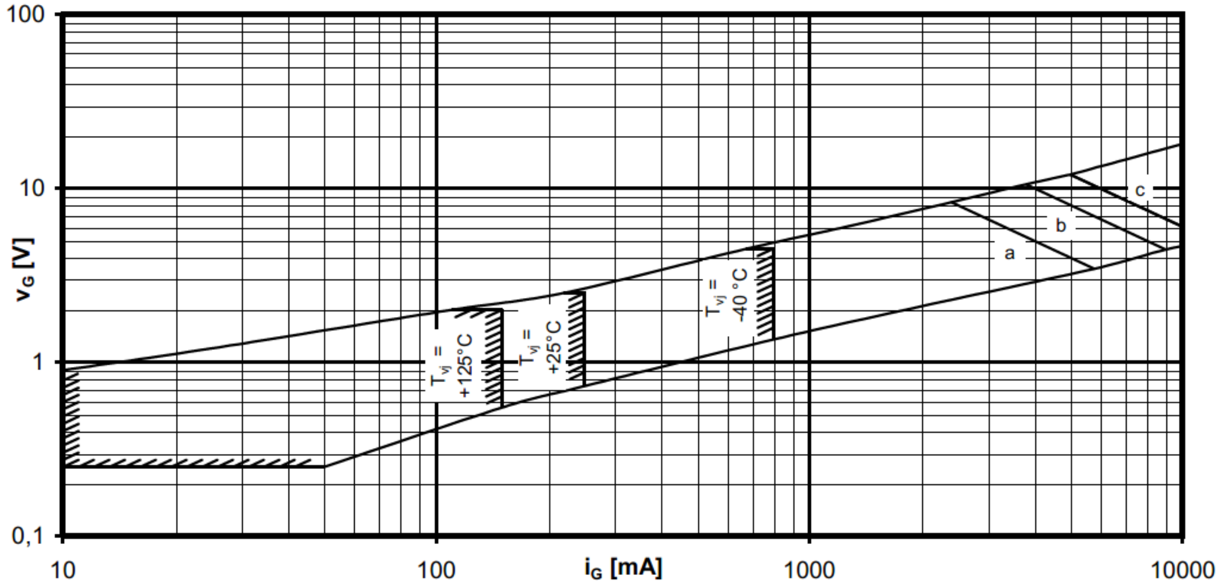


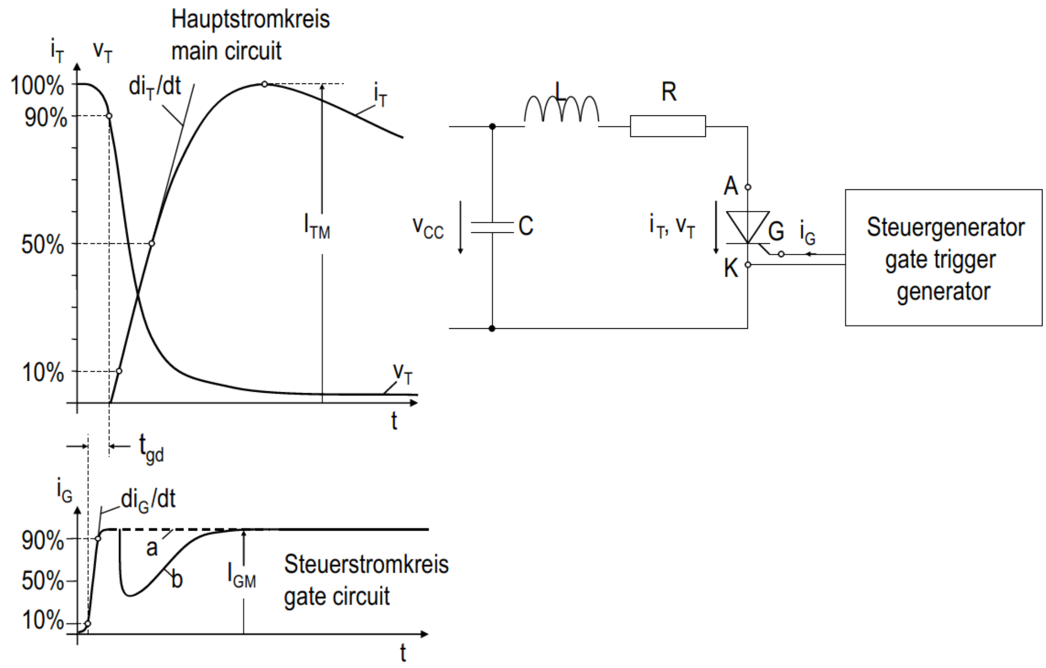
Figure 9. Example for control characteristic

The example shows the limits of statistical distribution of the input characteristics of a thyristor type (V_G=f(i_g) with trigger area for V_D=12 V). Within the distribution of the input characteristics, the temperature dependent trigger areas are detailed as well as the curves of the maximum permissible gate power dissipation P_{GM} (a: 20 W/10 ms, b: 40 W /1 ms, c: 60 W/0.5 ms).
The dynamic behavior under operational conditions may differ.

3.4 Dynamic gate current behavior under operational conditions

The turn-on process is initiated at forward on-state voltage v_D by a gate current with a slew rate di_G/dt and a magnitude i_{GM}. During the gate controlled delay time t_{gd} the blocking voltage across the thyristor drops to 90% (see Figure 10).
Initially there is only a small area around the gate area on the pellet that is conducting during turn-on. That leads to high current density and increased voltage (see Figure 6). A gate trigger pulse with a high peak current and a high di/dt supports proper turn on of the thyristor.

For thyristors with amplifying gates additional the voltage drop across the internal gate resistor in Figure 7 will influence the trigger current. Due to internal coupling this voltage also appears at the control terminals and, therefore, leads to an intermediate drop of the gate trigger current if the no load voltage of the trigger circuit is too low (see Figure 10).
To prevent the gate pulse from dropping too low, compensation by means of a higher open circuit voltage V_L of the trigger circuit may be necessary. That is important for thyristors with amplifying gate (see chapter 2.2). The main circuit cathode current di/dt may damage the auxiliary thyristor during the early turn on phase.
In special for low temperature applications, e.g. -40 °C, the open circuit voltage of the trigger circuit needs to be up to 30 V. The whole trigger behavior of thyristors becomes more sluggish at lower temperatures. The open circuit voltage can be lower, but the proper triggering needs to be checked for all application parameters during type test for the converter.
Additional in order to avoid any feedback to the trigger circuit, the trigger circuit needs to be equipped with a decoupling diode (see Figure 27).



Schematic representation of a thyristor turn-on process
a - gate current with turned off load circuit
b - gate current with steeply rising on-state current

Figure 10. Gate current influencing by anode current

3.5 Other important trigger requirements

The thyristor remains turned on only if anode current is above latching current I_L.

If the gate trigger current is too low, the thyristor may be damaged because of limited spreading of conducting area. This is called “soft firing”. Soft firing can also occur due to trigger pulses being too small or due to EMI.

For parallel or series connection of thyristors, high di/dt and synchronous trigger pulses are necessary in order to achieve balanced turn-on. Also, see the distribution of the gate control delay time values in Figure 11.

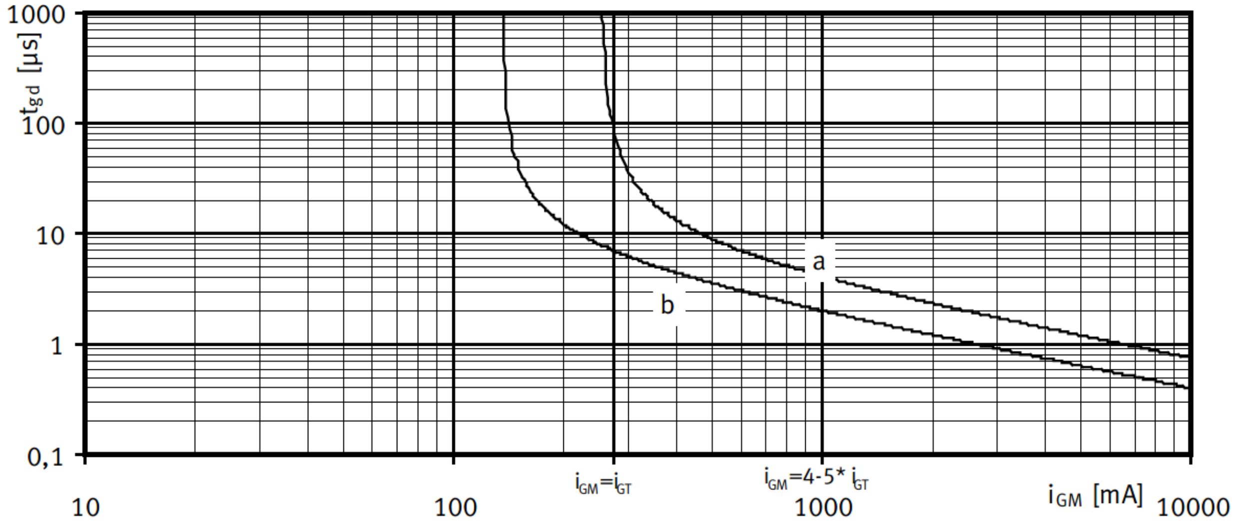


Figure 11. Typical dependence of the gate controlled delay time tgd and the maximum gate current iGM (a=max value, b=typ value)

t_{gd} is the period between the gate current reaching 10 % of its maximum value I_{GM} and the time when the anode-cathode voltage drops below 90 % of the applied forward off-state voltage v_D (see Figure 10, Figure 11). It reduces significantly with increasing gate current (see Figure 11). In high power thyristors the t_{gd} depends also on v_D. The value given in the data sheet is defined according to DIN IEC 60747-6 and is valid for T_{vj} = 25 °C and specified trigger pulse.

3.6 Recommended trigger current

In a normal application the design of the control circuit should be done in accordance with the control data, which is detailed in connection with the critical rise time of the on-state current, the gate control delay time and the latching current (see Figure 10). The minimum data from the datasheet for gate trigger current and gate trigger voltage is valid only for applications with low requirements with regard to critical current rise time and gate control delay time.

In normal applications, the gate current should be 4 to 5 times the value of i_{GT} to ensure safe operation even with high requirements for current rise time and gate control delay time. In critical applications, i_{GT} may be overdriven even harder than described before. For this, the gate current should be increased for a time (t_{GM} ≈ 10 to 20 µs) to 8 to 10 times the value of I_{GT} and then continue for a sufficient time t_G with a reduced amplitude.

The open circuit voltage of the trigger circuit should at least apply 30 V in order to assure a constant high gate current. Most trigger transformers offer an open circuit voltage of about 12 V only. It needs to be checked during type test whether the gate current (i_G) is above the gate current (I_{GT}) given in the datasheet and according to Figure 10.

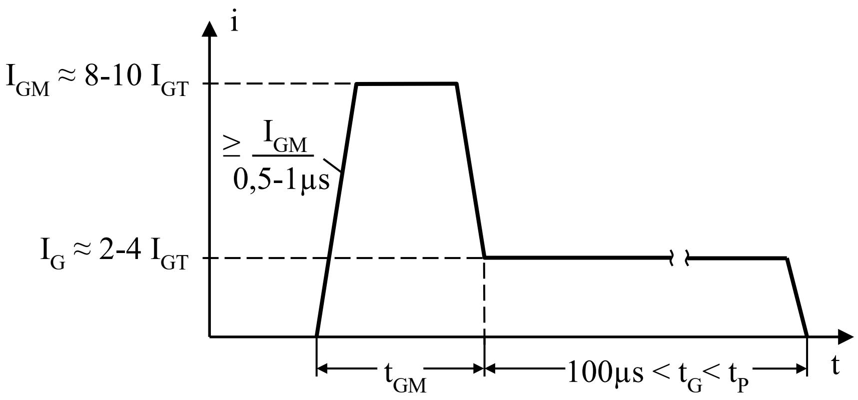


Figure 12. Recommended ideal trigger current for sophisticated applications

Terms used in this context are:

Abbreviation	Designation	Recommended value	Comment
I_{GT}	Gate current	Max. 0.12 to 0.35 A	Range for the major thyristor portfolio. Take the value from to datasheet of the applied thyristor
di_G/dt	Gate current slew rate	1 to 6 A/µs (In 0.5 to 1 µs to i_{GM})	Range for the major thyristor portfolio. According to datasheet of the applied thyristor
i_{GM}	Peak gate current	8-10*I_{GT} up to 3.5 A	Depends on thyristor type
t_{GM}	Peak gate current duration	10 to 20 µs	Depends on thyristor type and application
i_{G_roof}	Roof gate current	2-4* I_{GT} up to 1.4 A	Depends on thyristor type
t_G	Duration of the trigger pulse	30 to 100 µs	Depends on current rise time in load circuit
V_L	Open circuit voltage of the control circuit	>30 V	Lower value allowed if i_G does not drop below I_{GT} during turn on. See chapter 3.4
t_{G_min}	Absolute minimum gate trigger pulse duration	10 µs	Shorter pulses are not allowed, thyristor will not turn on completely and may be damaged
t_{gd}	Gate controlled delay time	As short as possible for large di/dt, series or parallel operated thyristors.	According to datasheet of the applied thyristor. See also Figure 11.

Table 4. Abbreviations and designations for trigger values

3.7 Measures to protect against EMI turn-on of thyristors

In power converters, steep current and voltage changes occur in the main circuit. There is a risk that interference pulses are generated at the control terminal of thyristors as a result of inductive or capacitive interference on control lines and control electronics. Thus, the thyristors can turn on unintentionally and cause a malfunction of the system. Conventional measures for reducing this interference and avoiding the glitches are twisting and if possible reducing the length of trigger wiring, as well as improved shielding of the firing transformer and control electronics. In addition, the gate circuit can be protected with resistors and capacitors (see Figure 13).

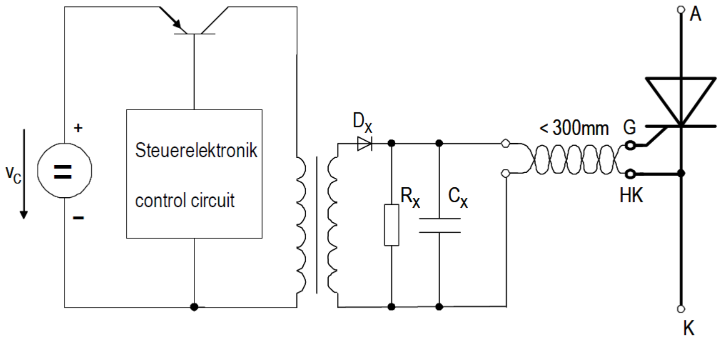


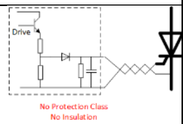
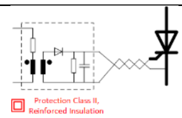
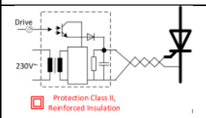
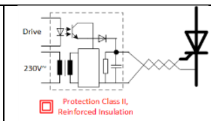
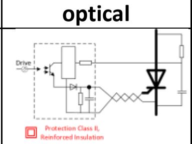
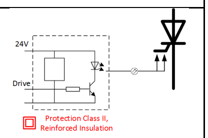
Figure 13. EMI protection for thyristor gate

For standard power thyristors, the following values are recommended:
- C_x = 10 to 47 nF
- R_x corresponding to $\tau_X = R_xC_x$ = 10 to 20 µs
- D_x fast diode

The discharge resistor R_x must not be omitted because otherwise some data of the thyristors may change, e.g. the critical voltage gradient $(dv / dt)_{cr}$. If the wiring adversely affects the course of the control current, this must be taken into account when dimensioning the control generator. See chapter 5 for more detailed information about gate driver design.

4 Thyristor trigger circuit concepts

Depending on the application area, different triggering solutions for thyristors are possible. In addition to providing the triggering energy, the trigger circuit also has to ensure the required insulation between line supply circuit and control circuit.

	Important trigger circuit concepts for thyristors					
	ETT					LTT
Concept	**Direct**	**Fully magnetical**	**Energy magnetical, drive signal optical**		**Energy decoupled, drive signal optical**	**Fully optical**
Trigger circuit						

Interface	Direct coupled	Firing trans-former (one core)	Transformer, Fiber Light Cable	Transformer, opto coupler	Direct coupled	Fiber Light Cable
Isolation for the drive signal	Not applicable	Reinforced isolation for transformer required	Fully isolated by optical fiber (reinforced)	Reinforced isolation by applicable opto coupler required	Fully isolated by optical fiber	Fully isolated by optical fiber
Isolation for trigger energy	Not applicable	Basic isolation for energy channel applicable if it is separated from UI. Otherwise reinforced insulation.	Basic isolation for energy channel applicable if it is separated from UI. Otherwise reinforced insulation.	Basic isolation for energy channel applicable if it is separated from UI. Otherwise reinforced insulation.	Not required	Not required
Drive signal	Electrical	Electrical	Optical (LED-, Laser Diode and POF[1], GOF[2])	Electrical	Optical (LED-, Laser Diode and POF, GOF)	Optical (Laser Diode and GOF)
Pulse pattern	Block, Pulse Train	Block, Pulse Train	Block, Pulse Train	Block, Pulse Train	Block, Pulse Train	Single Pulse, Pulse Train
Pulse length	0.5 ms, 33 µs, 10 kHz	0.5 ms, 33 µs, 10 kHz	0.5 ms, 33 µs, 10 kHz	0.5 ms, 33 µs, 10 kHz	0.5 ms, 33 µs, 10 kHz	10 µs, 10 µs, 6 kHz
Converter circuits (e.g.)	Single thyristors, half controlled circuits with common cathodes	B6C, W3C	B6C, W3C	B6C, W3C	B6C, W3C	B6C, W3C
Recommended operating voltage	LV ≤230 V rms ELV ≤65 V rms	LV and MV ≤6 kV rms	LV and MV ≤6 kV rms	LV ≤400 V rms	HV	HV

Table 5. Overview for thyristor trigger circuit concepts

4.1 Direct trigger circuits for ETTs (non isolated)

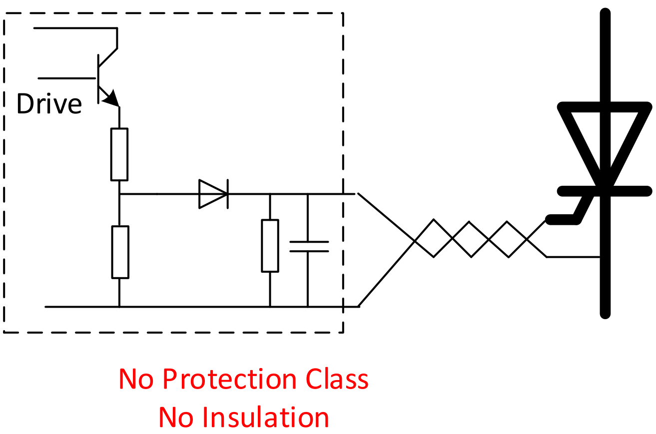


Figure 14. Direct triggering of a thyristor

[1] Plastic Optical Fiber
[2] Glass Optical Fiber

In low voltage thyristor converters with less interface functions to control systems isolation between controller and thyristor power stage is not common. It is applicable only for single thyristor or circuits with common cathodes (half controlled circuits). The control and gate drive circuit is connected directly to the cathodes of the thyristors. If necessary, required isolation needs to be done for the user interfacing opto couplers. Trigger current requirements needs to be fulfilled according the application needs.

4.2 Isolated trigger circuits for ETTs

The most important advantage of the isolated triggering circuit is the isolation between user interface/controller and thyristor power stage (line supply circuit). The requirement depends on application, grid system, line voltage and installation position. Designing the correct isolation is a challenge for some applications. It has to meet the requirements for a safe separation. Especially when it comes to medium voltage applications and at the same time the requirements of overvoltage category IV have to be met (see IEC 60950, IEC 60664-1). The latter can only be operated with magnetic pulse transducers or fiber optics. Opto couplers are limited regarding clearance and creepage capabilities. High-voltage systems require trigger energy decoupling from the anode voltage based on cathode potential and thyristor triggering by fiber optics or direct light-triggered thyristors.

Requirement	**Characteristics**	**Benefit**	**Remark**
Safe isolation	Isolation according to IEC60950, 50178, 60664-1	No risk about electrical shock at the user interface	
Small coupling capacity	High immunity	No unplanned turn on for thyristors, no soft firing	
Small stray inductance	Trigger current with high di/dt		
Open circuit voltage	>30 V	Under all operational circumstances safe turn on for thyristors	
Small size	Small voltage time area		Needs to be supported by the thyristors. Small t_{gd}. See chapter 3.6
High isolation voltage	Clearance, creepage, dielectric and CTI according insulation requirements	No risk about electrical shock at the user interface	Isolation according to IEC60950, 50178, 60664-1
Transferring high short time power	Good coupling between both transformer sites. Interface between pulse transformer and thyristors needs to be optimized.	Fast and safe turn on for thyristors	
Operation temperature between -40 °C and 85 °C.		The thyristor can be triggered according its operational parameters.	Most critical operation point is -40 °C. It requires high trigger current and fast di/dt for I_G.

Fulfilling applicable general and product standards e.g. IEC50178 for drives	Correct overvoltage category, right pollution degree, right environmental protection	Stable and safe operation for a long time	

Table 6. Requirements for isolated triggering circuits

4.2.1 Optical trigger circuits for ETTs

4.2.1.1 With opto coupler

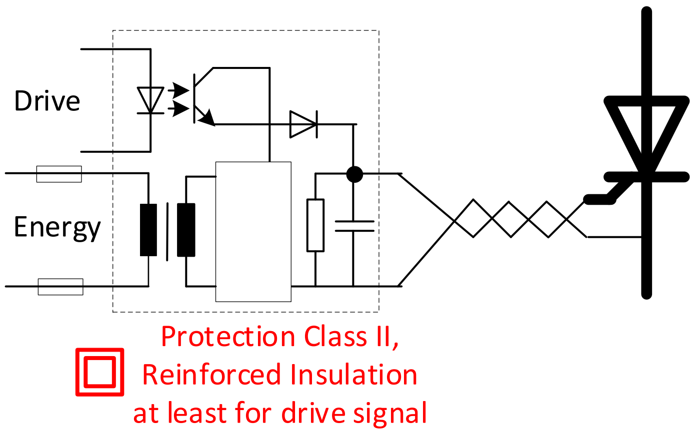


Figure 15. Thyristor triggering with opto coupler

Opto coupler triggering allows long trigger pulses. The operating voltage is limited to e.g. 400 V_{rms} because of limited availability for opto couplers with reinforced insulation.

4.2.1.2 With optical transmitter, fiber and receiver

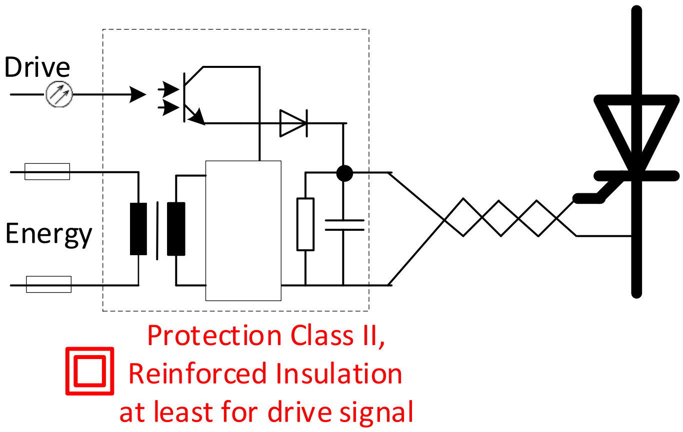


Figure 16. Thyristor triggering with optical fiber

Triggering by LEDs, Plastic Optical Fibers (POF) and optical receivers allows long trigger pulses and Electromagnetic Interference (EMI) protected interfaces between the trigger board and the controller for short distances. That concept is also be used for series connected thyristors in Soft Starters. In that case the energy transfer will be done via a common current source.

4.2.1.3 With optical transmitter, fiber, receiver and trigger energy decoupling from the anode voltage

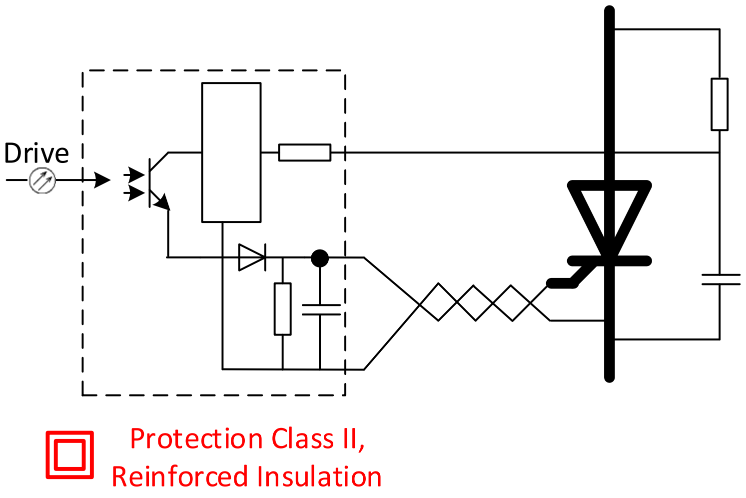


Figure 17. Optical ETT triggering with energy decoupling from power circuit

Each electrically triggered thyristor (ETT) requires a trigger board. The trigger energy is taken from the snubber circuit. It allows long trigger pulses. It requires a minimum anode cathode voltage and can provide optional thyristor status information by adding a feedback signal circuit. This trigger concept will be used for medium and high voltage applications. The Glass Optical Fiber (GOF) works as isolated trigger channel.

4.2.1.4 Direct optical triggering with laser diode and optical fiber

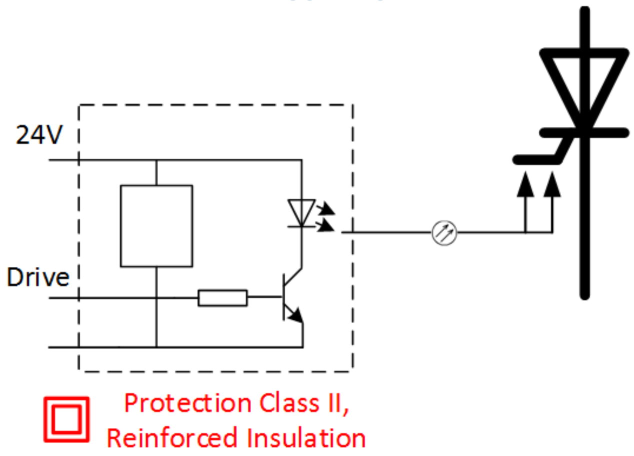


Figure 18. Direct light triggered thyristor

The direct light triggered thyristor (LTT) offers additional protection functions. It is described in detail in AN 2018-07, Triggering LTT's" [7].

4.2.2 Magnetic trigger circuits for ETT's

4.2.2.1 Concepts for block pulses

We differentiate between trigger transformers and trigger circuits. The trigger circuits include additional passive or active components like diodes, resistors etc.

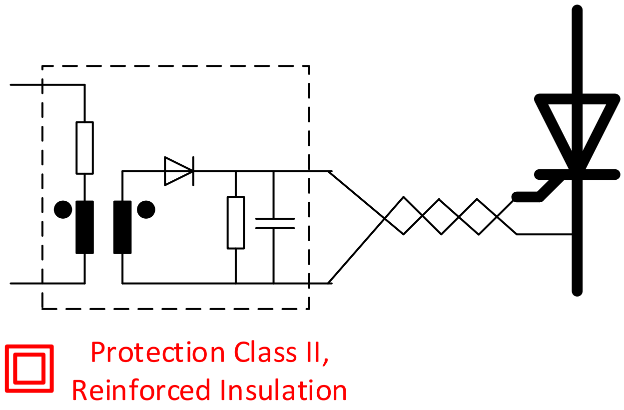


Figure 19. Thyristor triggering with pulse transformer and additional passive components

This trigger circuit combines the isolation of the trigger signal and trigger energy with one component, the trigger transformer. It is a simple trigger concept and works for almost all applications. The concept is limited by the isolation capability of the trigger transformer. In the past only trigger transformers for long pulses (block pulses; large voltage time area) were used, e.g. 0.5 ms to 1 ms for B6C circuits and 10 ms for W1C circuits (see chapter 7 for application specific details). If thyristor applications require more time for proper latching due to low rising anode current, block pulses are a reliable trigger solution. It is a relative expensive and space consuming solution. Transformers for block trigger pulses are larger and have a larger coupling capacitance (Figure 20). They require a shield between primary and secondary winding. The shield needs to be grounded (see Figure 27, see chapter 5).

Examples for this concept are trigger circuits ZB1 and ZB10. Those are designed for mounting on the cooling block to achieve the shortest gate leads. Required clearance and creepage distances can be easily achieved.

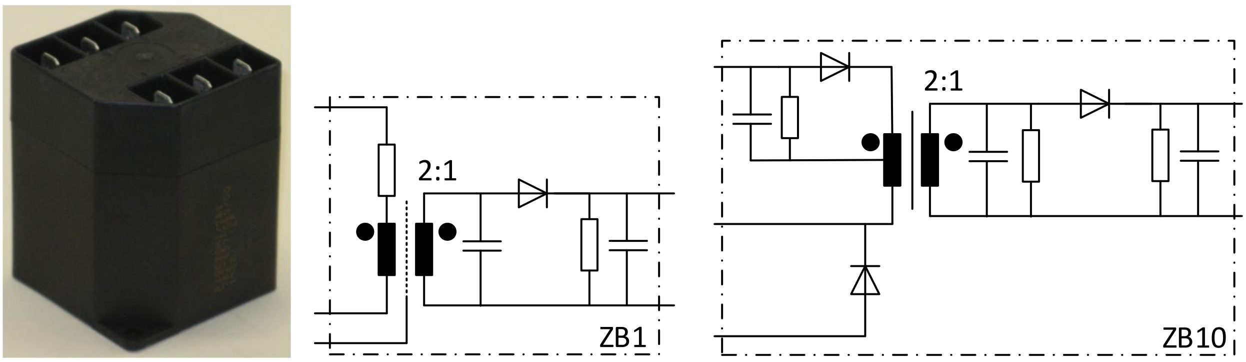


Figure 20. Trigger circuit ZB1 for 1 ms, ZB10 for 10 ms pulse duration time, 690 V line voltage (H*W*D = 60*40*40mm)

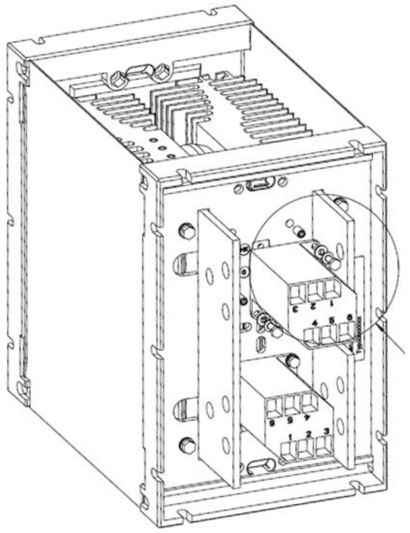


Figure 21. Trigger circuit ZB1 mounted on a cooling block K0.08F

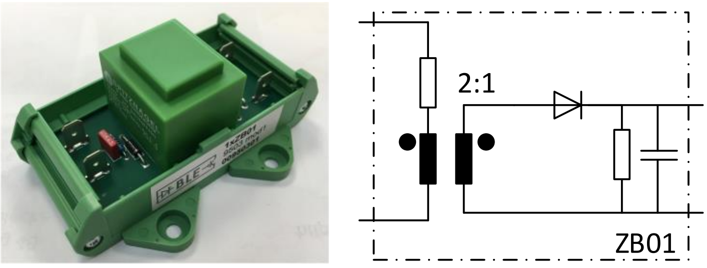


Figure 22. Further example: Trigger circuit ZB01 for 1ms pulse duration time, 500Vrms line voltage (H*W*D = 36*85*65mm)

4.2.2.2 Concepts for pulse trains

Applications with well-known commutation behavior can be triggered with short pulses and therefore smaller trigger transformers. To achieve save triggering during the planned conduction time the transformer needs to be fed with pulse trains. Trigger transformers for pulse trains are smaller and offer very low coupling capacitance. Figure 23 shows an example for a pulse train trigger transformer from VAC for PCBA mounting [4]. The voltage time area is about 250 µVs and the pulse duration time is about 20 µs. The specification follows the concept for typical trigger circuit design (see chapter 5).

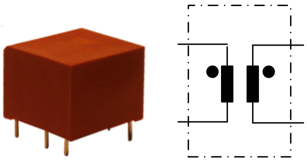


Figure 23. Trigger transformer T60403-D4721-X005 for 10 kHz pulse train, 500 Vrms line voltage (H*W*D = 13.5*17*18 mm)

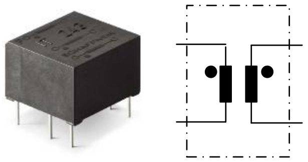


Figure 24. Trigger transformer IT 258 for 10 kHz pulse train, 750 Vrms line voltage (H*W*D = 11.3*17.6*16.7 mm)

See Table 8 for details about trigger circuits and trigger transformers.

4.2.2.3 Concepts for continuous triggering

Applications with thyristors in DC circuits may require continuous trigger signals. In general, the pulse train concept should also be applicable, but most of the simple magnetic trigger concepts are not designed for continuous load. They send trigger pulses usually only for one sine half wave of the line voltage. During the other half wave, they are not in operation.

Examples for this concept are trigger circuits TGD1 [10] and GD18008-T [18]. The trigger energy and the trigger signal are led through the trigger transformer. The trigger transformer gives the isolation between power circuit and control circuits. GD18008-T provides an optical input for the trigger signal. In that case at least the trigger signal has a reinforced isolation. The overall isolation coordination needs to be checked in detail.

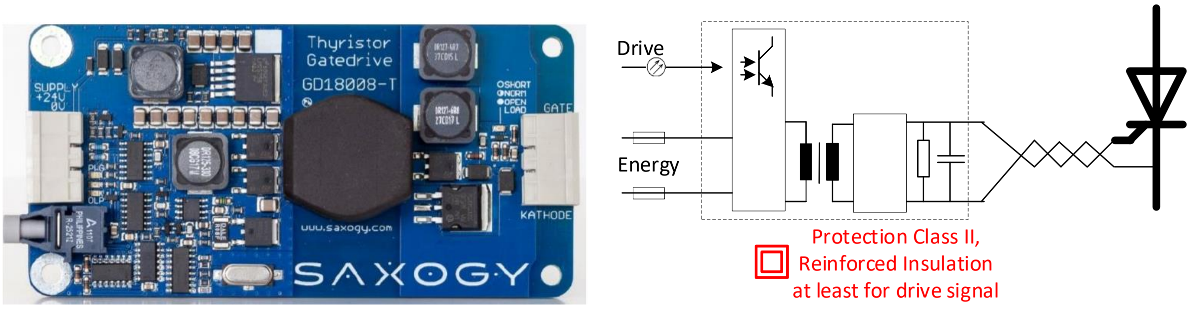


Figure 25. Trigger Circuit GD18008-T for continuous trigger signals

4.3 Overview about trigger circuits and their application areas

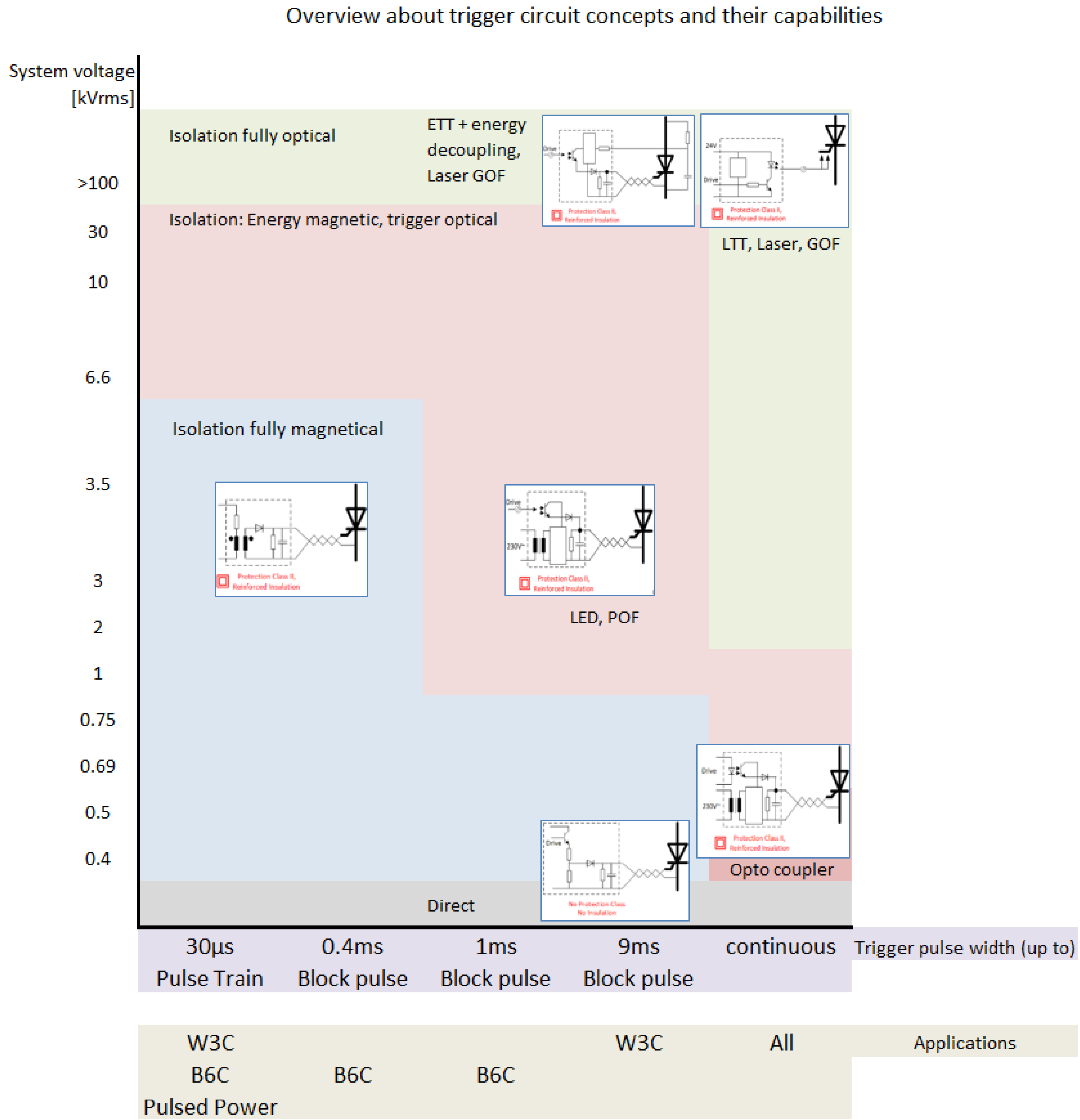


Figure 26. Trigger circuits and their capabilities

5 Proposal for a typical isolated trigger circuit for modern ETTs

Figure 27 shows a typical block trigger circuit for an ETT.
The feeding voltage for the trigger transformers primary side needs to be adjusted according to the transformer ratio and the application needs. See chapter 7.
The concept supports a leading current peak for the gate current (optional peak generated by R_{G2} and C_{G2}). The differentiator can also be arranged on the low-voltage side of the trigger transformers. The shield in the transformer is required for large trigger transformer to lower the capacitive interference between power unit and control unit.

The cable between trigger unit and thyristor needs to be twisted to increase the EMI capability. The trigger transformer needs to be designed for reinforced insulation, Protection Class II according EN 61140.

Protection Class II,
Reinforced Insulation

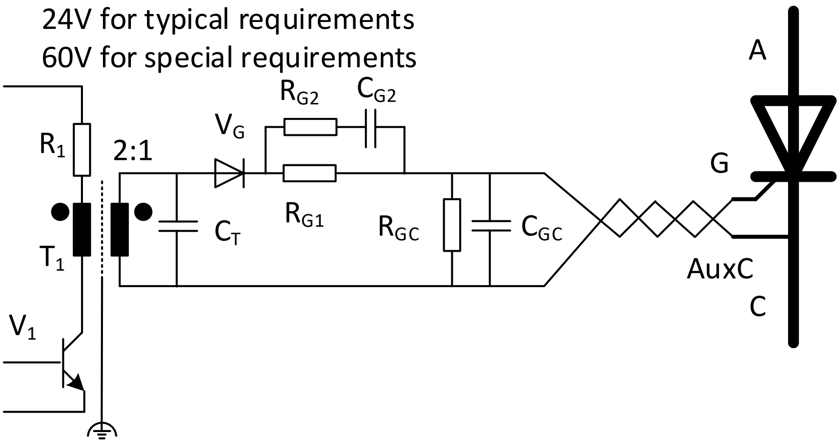


Figure 27. Specification for an isolated trigger circuit for ETT's

Part	Designation	Remark	Typical design	Reinforced design	
T_{vjop}	Operational junction temperature	From application	0 to T_{vjmax}	-40 to T_{vjmax}	°C
di/dt_{op}	Operational di/dt load circuit	From application	< 0.15 di/dt_{cr}	up to di/dt_{cr}	A/µs
V_{supply}	Trigger circuit supply voltage	Depends on transformer ratio	24	60	V
V_L	Trigger unit open circuit voltage	Depends on transformer ratio	12	30	V
R_1	Current limiting resistor for V1	Depends on V1	4.7	6.8	Ohm
$T_{1\ ratio}$	Trigger transformer with shield	shield optional	2:1	2:1	
t_{Pulse}	Trigger pulse width		30	100	µs
t_{GM}	Trigger peak pulse with		10	20	µs
U^*t_{T1}	Voltage Time Area T1	Depends on transformer ratio	> 0.72	>6	mVs
V_1	Trigger transistor to be driven by controller	MOS recommended	>5 A, > 100 V	>10 A, >200 V	
C_T	Resonance capacitor for T1 to achieve better dv/dt, di/dt for the gate current		optional	Needs to be optimized for the trigger transformer	nF
V_G	Diode for feedback current protection		Fast diode >100 V, 5A	Fast diode >100 V, 5A	

R_{G1}	Current limiting resistor for gate roof current	Depends on thyristor	e.g. 6.8	e.g. 6.8	Ohm
R_{G2}	Current limiting resistor for gate peak current	Depends on thyristor	optional	e.g. 6.8	Ohm
C_{G2}	Capacitor for peak current design	Depends on thyristor	optional	5.6	µF
R_{GC}	Resistor to increase EMI capability		$\tau_X = R_x * C_x$ = 10 to 20 µs		Ohm
C_{GC}	Capacitor to increase EMI capability		10-47	10-47	nF
$C_{T\_coupling}$	Transformer coupling capacity		<100	<100	pF
P_D	Partial discharge	Depends on grid system (TN, TT, IT) and line voltage to ground	Free of partial discharge up to highest operational peak voltage	Free of partial discharge up to highest operational peak voltage	
V_{isol}	Insulation test voltage	According to EN61140, EN60664-1, EN50178	Protection Class II	Protection Class II	

Table 7. Reference design for an isolated trigger circuit

6 Implementation of typical ETT triggering for the whole control channel

Figure 28 shows the whole trigger channel starting from phase shift control logic and ending on the thyristors gate. The mode of action of the entire signal path is coordinated in detail.

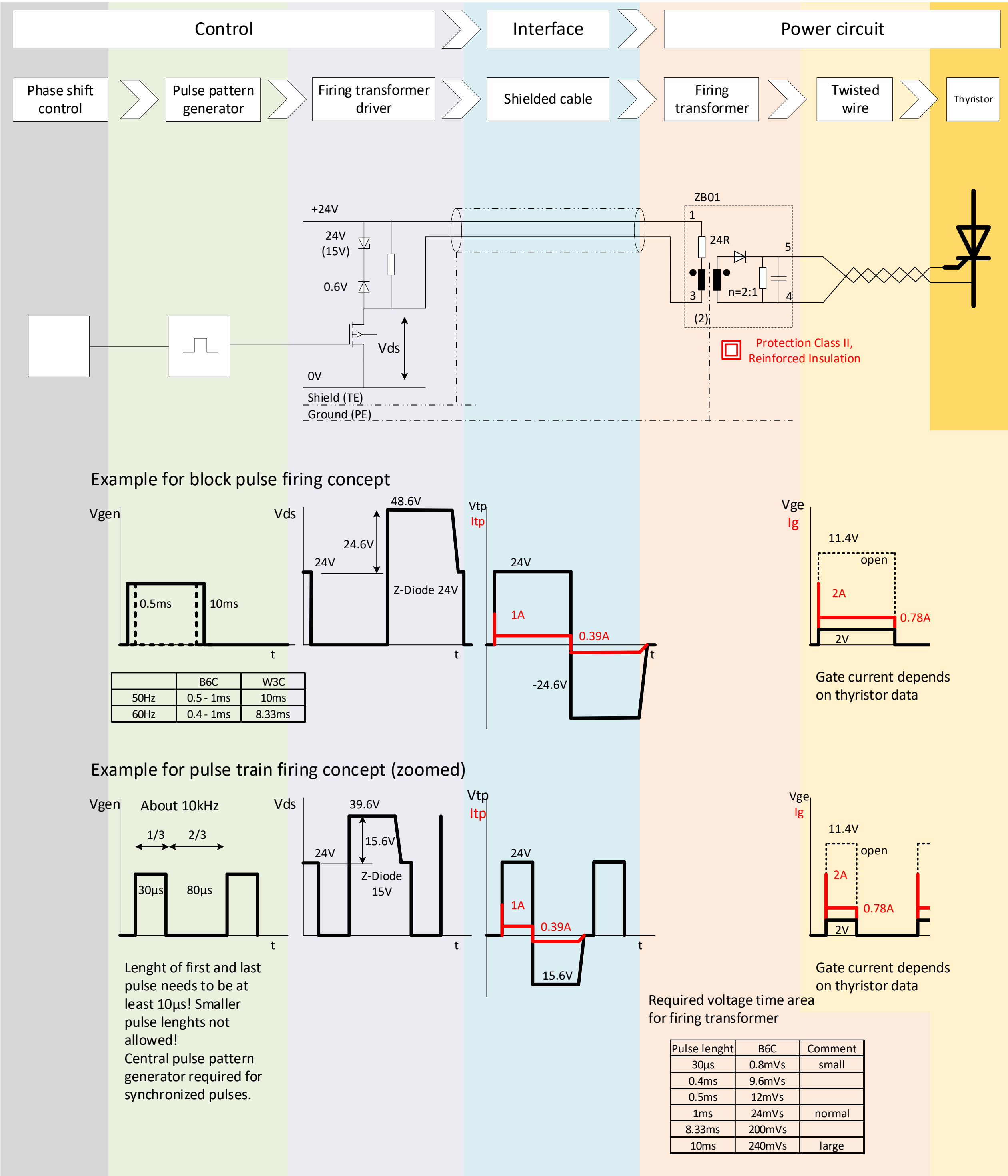


Figure 28. Electrical triggering with pulse transformer, the whole control channel

7 Application requirements

7.1 Basics for B6C power converters

When controlling the thyristors of the B6C rectifier, there are a few things to keep in mind. In the B6C full bridge circuit, the current always flows through two series-connected thyristors. The current commutates to another thyristor every 60 °. To establish a current flow, two thyristors must be triggered synchronously. In addition, the latching current of the thyristor must be achieved and the holding current must not be undershot. To ensure this, each thyristor in the B6C circuit must receive at least two trigger pulses. One at the beginning of its 120 ° conduction time and a 60 ° follow pulse [3]. The 60° follow up pulse is the first pulse of the corresponding thyristor in the commutation group. The trigger pulse can be realized as a block pulse or as a pulse train. The pulse length should be 9°. The applicable trigger pulse depends on thyristor characteristic and on load current behavior.

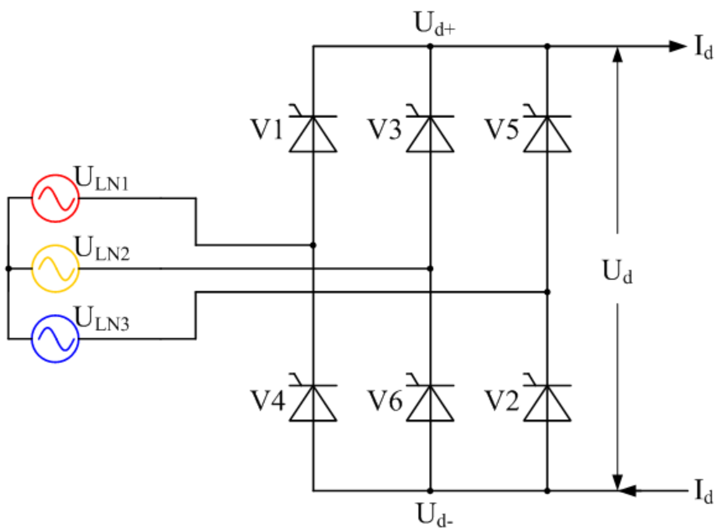


Figure 29. Three-phase voltage source and B6C circuit

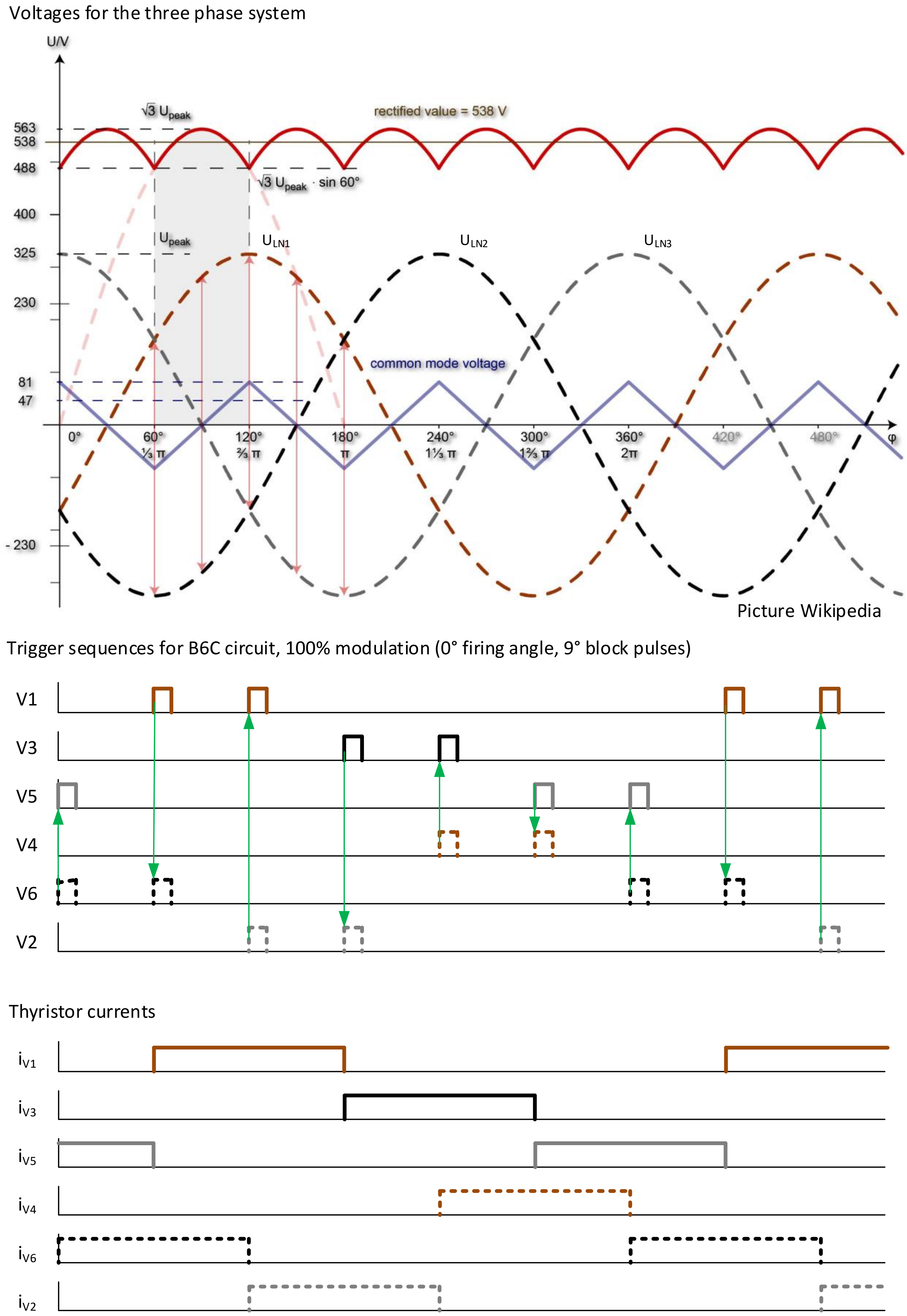


Figure 30. Voltages in the three-phase system, trigger sequences for B6C and thyristor currents

7.2 Implementation of trigger pulses for the B6C circuit

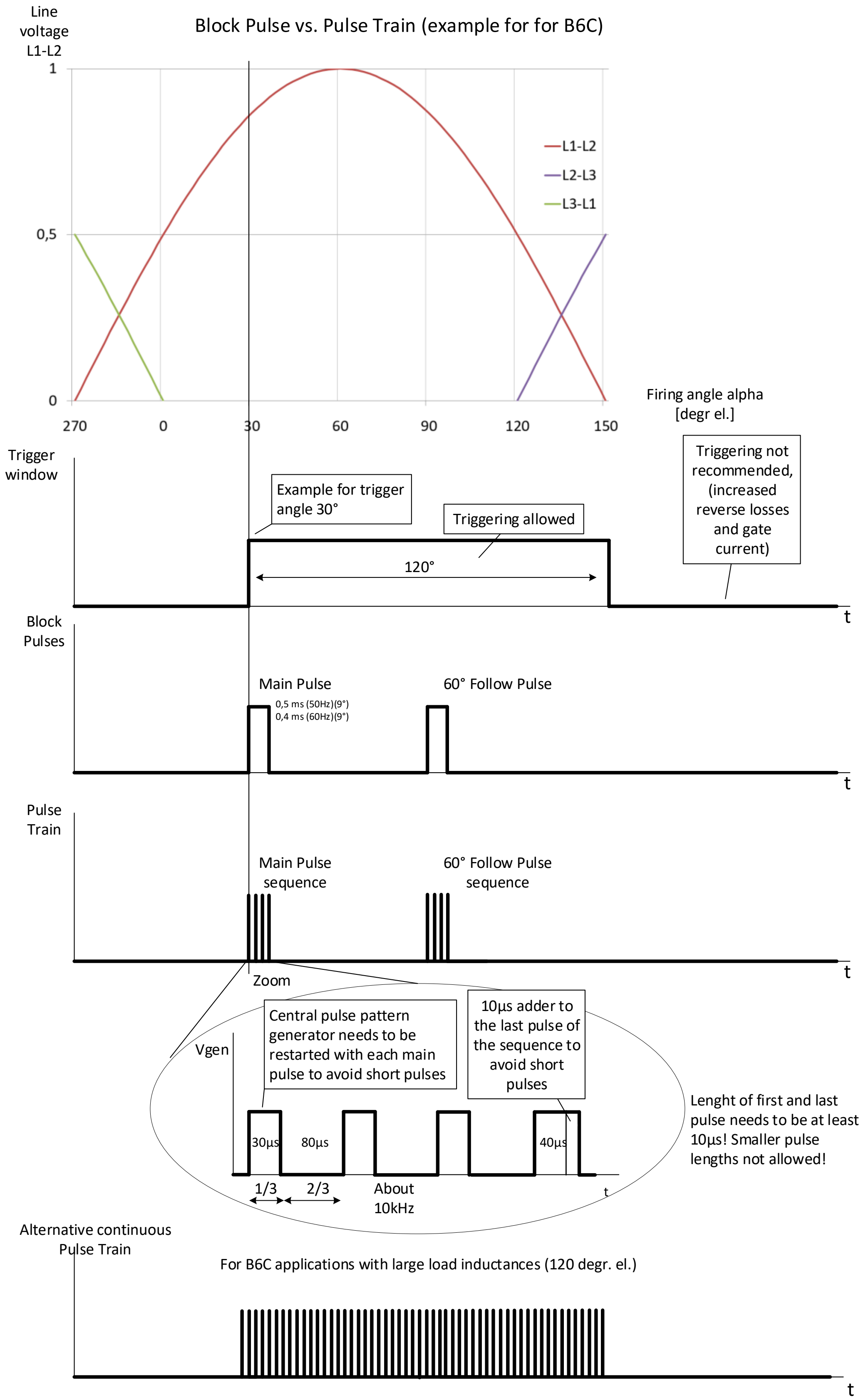


Figure 31. Block pulse and pulse train triggering for the B6C application

7.3 Trigger pulses for the W1C or W3C

Thyristors in W1C and W3C circuits require longer pulses for proper triggering. The thyristors should receive firing pulses during the whole conduction time (10 ms at 50 Hz or 8.33 ms at 60 Hz). Only then the anode-current flow is ensured. If short single pulses (e.g. 1 ms) are used, W1C or W3C may not be able to handle the current flow due to possibly low load current. Trigger transformer ZB10 (Figure 20) is designed for 10 ms pulse length. Alternative W1C and W3C can be triggered via pulse train with small trigger transformer (Figure 23).

8 Requirements for the control unit

All required protection times should be generated by the main pulse pattern generator. Generating of protection times in the trigger board may lead to a time offset in the whole phase control. The whole trigger channel must ensure short-pulse suppression. The pulses for all thyristors need to be synchronized; otherwise the load current cannot start flowing. The thyristors should not be triggered while the thyristors are subjected to a reverse voltage.

9 Examples for applicable trigger transformers / trigger circuits

The trigger systems from pulse type “Pulse Train” and “Block” are usually designed for use in 50/60 Hz AC converters. Please check in detail whether the trigger system fits to your application or not. Load type: Resistive, inductive.

Trigger transformer	Nominal line voltage [V_{rms}]	Trigger concept Energy / Signal	Pulse type, length t_G	Supply voltage V_{Supply}	Open circuit voltage V_L [V]	Design, remark
T60403-D4721-X005 *) Figure 23 [4]	500	Fully magnetical, passive	Pulse Train 20 µs	24 V_{avg}	12	Typical, transformer only
ZB01 **) Figure 22	500	Fully magnetical, passive	Block, 1 ms	24 V_{avg}	11.4	Typical, trigger circuit
ZB1-2365 Figure 20	690	Fully magnetical, passive	Block, 1 ms	24 V_{avg}	11.4	Typical, trigger circuit
ZB1-12526 Figure 20	690	Fully magnetical, passive	Block, 0,4 ms	150/60 V	22/8.8	Reinforced, trigger circuit
ZB10 **) Figure 20	690	Fully magnetical, passive	Block, 10 ms	24 V_{avg}	11.4	Typical, trigger circuit
GD18008-T *****) Figure 25	690	Fully magnetical, optical input (POF)[3], active	Cont.	24 V_{avg}	30	Reinforced, trigger circuit,

[3] Plastic Optical Fiber

IT258 ****) Figure 24 [15]	750	Fully magnetical, passive	Pulse train 20 µs	24 V_{avg}	12	Typical, transformer only
ZB1 **) Figure 20	1000	Fully magnetical, passive	Block, 1 ms	24 V_{avg}	11.4	Typical, trigger circuit
TGD1 ***) Figure 32	1000	Fully magnetical, active	Cont.	15 V_{avg}	30	Reinforced, trigger circuit, feedback signals
ZHV400-2 **) Figure 33	2000	Fully magnetical, passive	Block, 0.4 ms	24 V_{avg}	11.4	Typical, trigger circuit
IT364 ****) Figure 34	3000	Fully magnetical, passive	Block, 0.5 ms	24 V_{avg}	24	Typical, transformer only
ZB1/10-3500-LWL **)	3500	230V transformer/ POF[4], active	Block, 9 ms	230 V_{rms}	11	Typical, trigger circuit
2xZB1/10-3500-LWL **) Figure 35	3500	230V transformer/ POF, active	Block, 9 ms	230 V_{rms}	11	Typical, trigger circuit. Two channel
ZB1/10-6600-LWL **)	6600	230V transformer/ POF, active	Block, 9 ms	230 V_{rms}	11	Typical, trigger circuit
2xZB1/10-6600-LWL **) Figure 36	6600	230V transformer/ POF, active	Block, 9ms	230 V_{rms}	11	Typical, trigger circuit. Two channel
Power Supply SW32-24D10A, Supply Cable HSC30, Decoupling Unit DU15-15G. Figure 37 Optical fiber based trigger circuit like GD18008-T. Figure 25	30000	24V isolated power supply/ POF, active	Cont.	15 V_{avg}	30	Reinforced, trigger circuit, feedback signals

Table 8. Examples for applicable trigger transformers and trigger circuits

*) Product of VAC, Hanau, Germany
**) Product of BLE, Warstein, Germany
***) Product of IB Billmann, Emskirchen, Germany
****) Product of Schaffner Group, Luterbach, Switzerland
*****) Product of Saxogy Power Electronics, Chemnitz, Germany

[4] Plastic Optical Fiber

9.1 Special trigger circuits and transformers

9.1.1 TGD1

The TGD1 from Ing. Büro Billmann provides long pulses and status signals [10]. It is also applicable for thyristors in DC applications. See Figure 32.

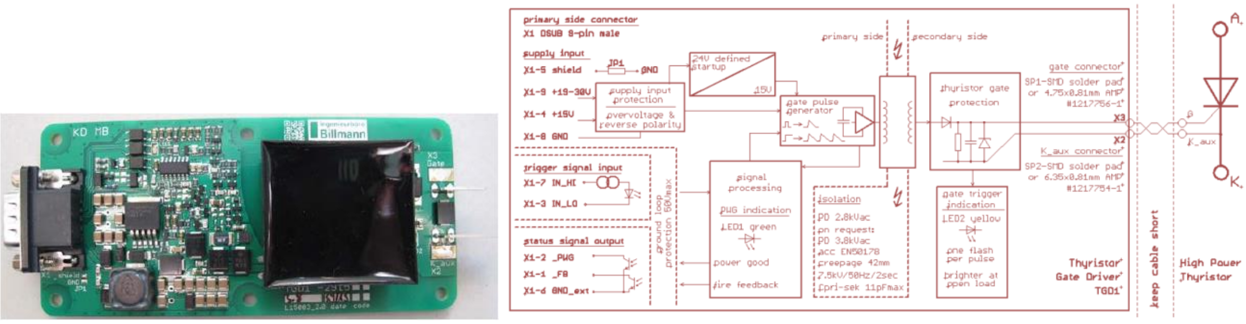


Figure 32. Trigger circuit TGD1 for long pulses and status signals

9.1.2 ZHV400-2

The ZHV400-2 from BLE was designed for block pulses and 2kVrms line voltage and provides a shield between both windings [11]. See Figure 33.

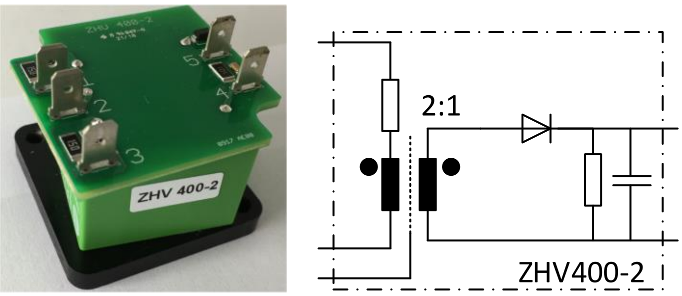


Figure 33. Trigger circuit ZHV400-2 for blocks pulses and 2 kVrms line voltage

9.1.3 IT364

The IT364 from Schaffner was designed for block pulses and 3 kVrms line voltage.

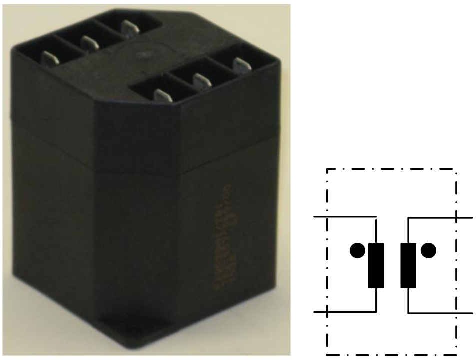


Figure 34. Trigger transformer IT364 for block pulses and 3 kVrms line voltage

9.1.4 2xZB1-10-3500-LWL

The 2xZB1-10-3500-LWL from BLE was designed for block pulses, 3.5 kVrms line voltage and driving via POF[5] [13]. See Figure 35. Also available as single channel version ZB1-10-3500-LWL.

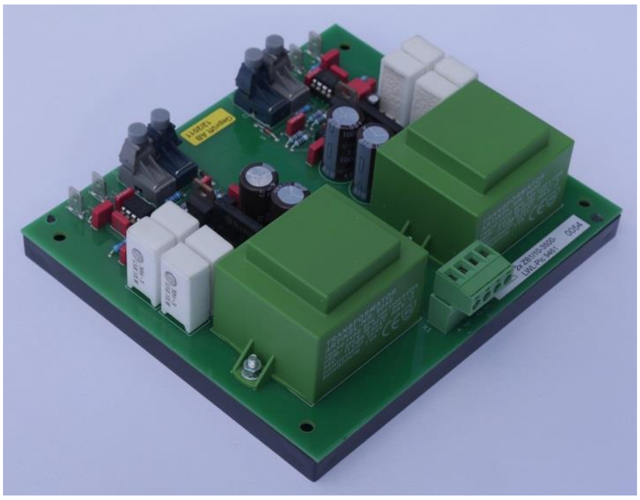


Figure 35. Trigger circuit 2xZB1-10-3500-LWL

9.1.5 2xZB1-10-6600-LWL

The double channel trigger circuit 2xZB1-10-6600-LWL from BLE was designed for block pulses, 6.6 kVrms line voltage and driving via POF (Plastic Optical Fiber) [16]. See Figure 36. Also available as single channel version ZB1-10-6600-LWL.

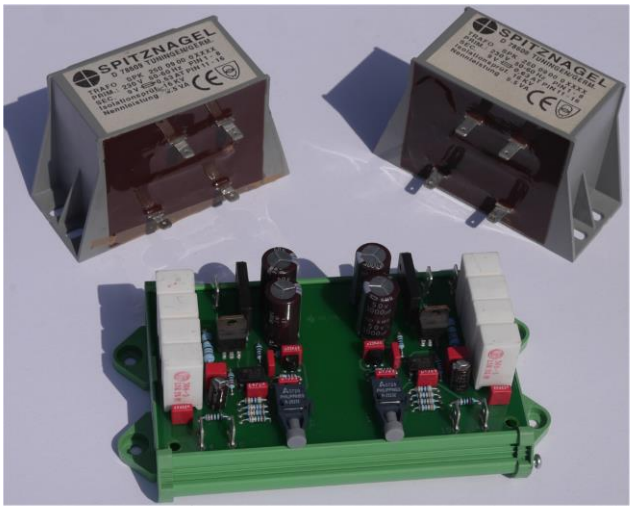


Figure 36. Trigger circuit 2xZB1-10-6600-LWL

9.1.6 Isolated current loop power supply system

The isolated current loop Power Supply system from Siebel supports series connected thyristors in medium voltage applications. It consist from Power Supply SW32-24D10A, Supply Cable HSC30 and Decoupling Unit DU15-15G [17]. See Figure 37

[5] Plastic Optical Fiber

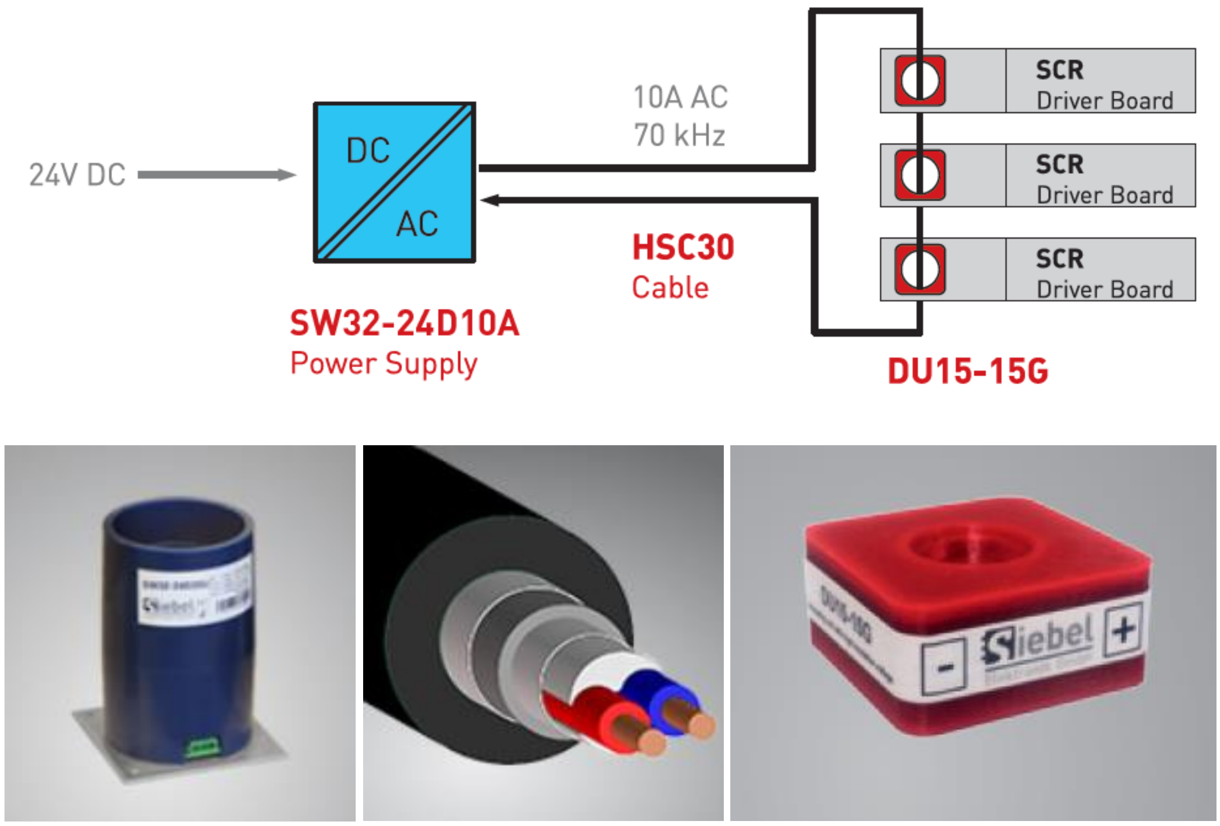


Figure 37. Current loop power supply system [17]

9.2 Overview about trigger units and their application areas

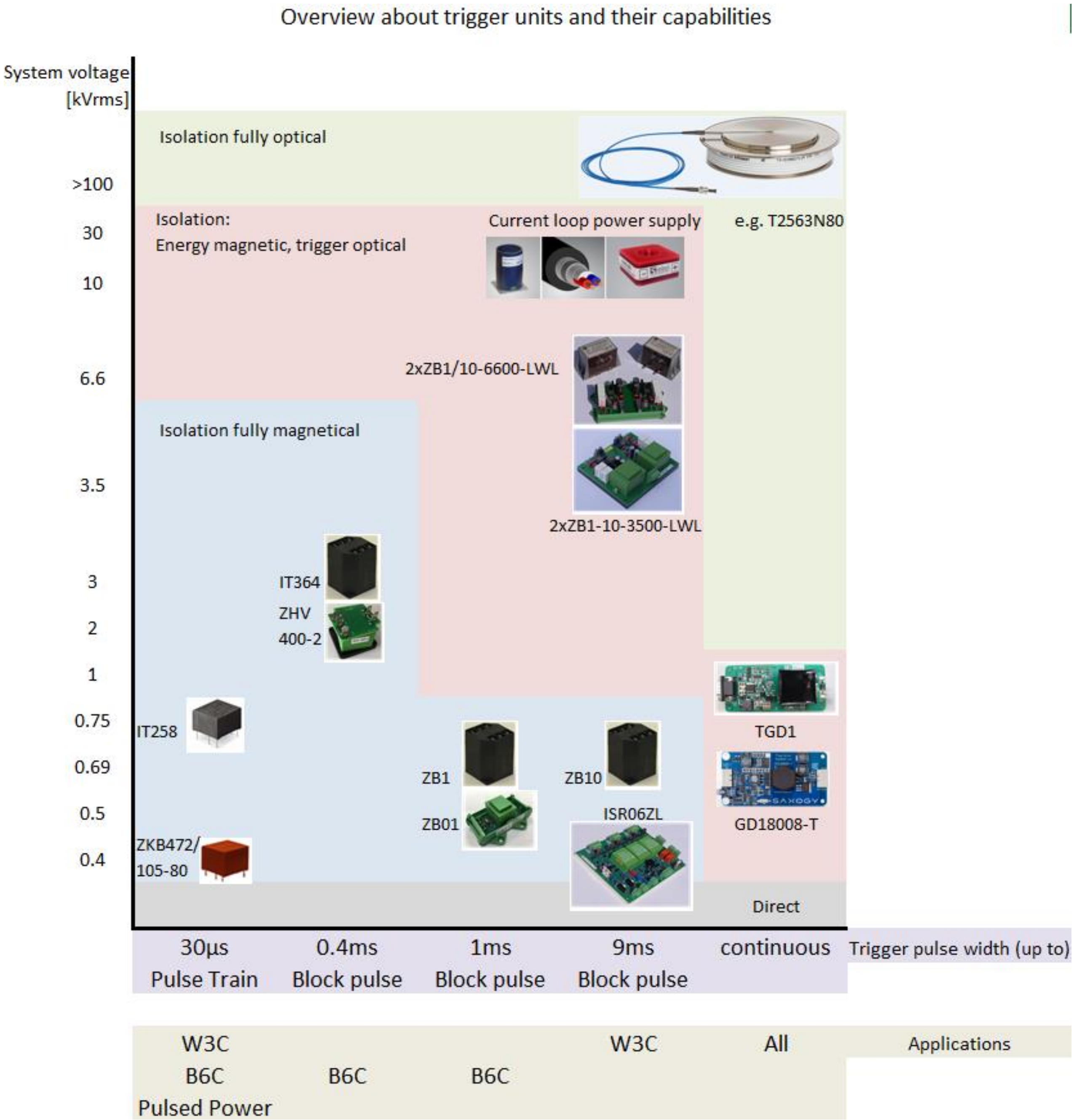


Figure 38. Trigger units and their capabilities

10 Examples for controller

10.1 All-in-one controller

The Three-Phase Control System ISR06ZL is able to control all common rectifier circuits such as B6C, M3.2C, M6C, B6HC, W3C for resistive or inductive loads up to 400 Vrms line voltage. It includes control electronics and trigger transformers on one PCB which is mounted on a base plate. The controller provides block pulses up to 10 ms [12]. The trigger concept is magnetic /magnetic (Energy / Signal).

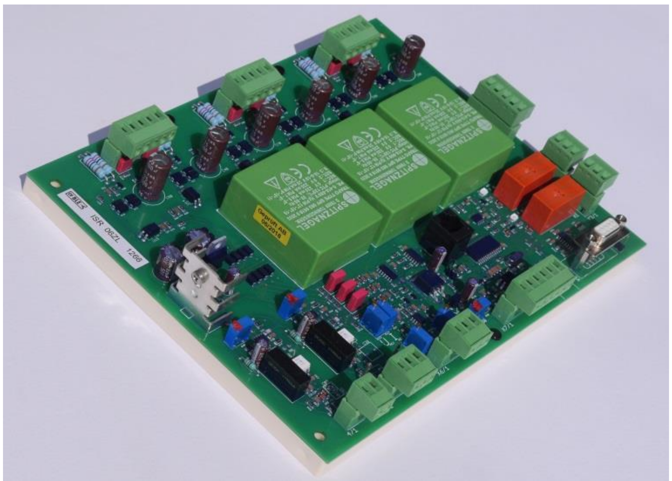


Figure 39. Controller and trigger circuit ISR06ZL for BLE for thyristor converters

10.2 Controller without trigger circuits

The Three-Phase Control System ISR06 is able to control all common rectifier circuits as B6C, M3.2C, M6C, B6HC, W3C for resistive or inductive loads. It includes control electronics on a PCB which is mounted on a base plate. The controller provides block pulses up to 10 ms [14].
The trigger concept is magnetic / magnetic (Energy / Signal). These are to use separate trigger transformers.

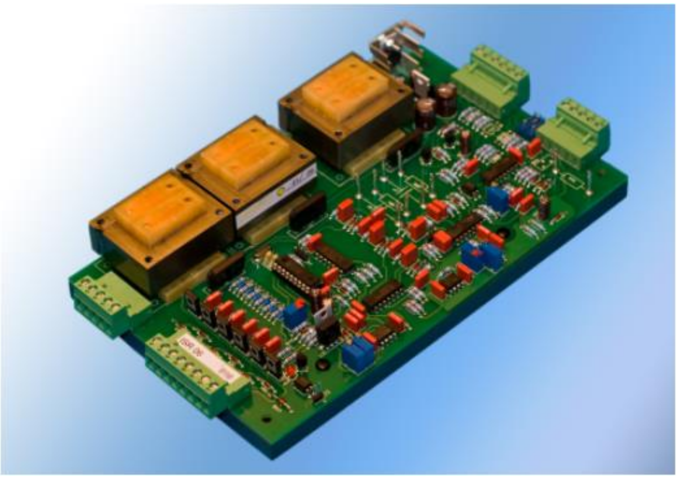


Figure 40. Controller ISR06 from BLE for thyristor converters

11 Standards

A thyristor assembly is not a complete product.
An assembly is defined as semiconductors mounted on heat sinks and so cannot be a fully functional end product. Because of that, some basic standards needs to be applied. The IEC60664 for insulation coordination is the most important standard. It describes clearance and creepage distances.
Furthermore parts of the product standards IEC 62040-3 for UPS and IEC/UL 61800-5-1 for VSD (variable Speed Drive) and the EN 60146-1-1 Semiconductor converters – General requirements and line commutated converters can be applied.

12 Abbreviations

The abbreviations are explained in AN2012-01 in detail [1]

13 Table Directory

14 Pictures Directory

15 Supplier for controller and trigger circuits

BLE, Warstein, Germany
Ing. Büro Billmann, Emskirchen, Germany
VAC, Hanau, Germany
Schaffner, Luterbach, Switzerland
Saxogy Power Electronics, Chemnitz, Germany
Siebel Elektronik, Kreuztal, Germany

16 Brands

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19 Sources

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[4] VAC, T60403-D4721-X005, Data Sheet, https://www.vacuumschmelze.com/Assets-Web/4721-X005.pdf
[5] Semikron International GmbH, U. Nicolai, “Thyristor Triggering and Protection of Diodes and Thyristors, AN 18-002”, Nürnberg, Germany, 2018

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[7] Infineon Technologies Bipolar GmbH & Co. KG, “AN2018-07 – Triggering LTT’s”
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[9] IEC 60664-1
[10] Ing. Büro Billmann, TGD1 Preliminary Data Sheet
[11] BLE, ZHV400-2, Data Sheet trigger circuit
[12] BLE, ISR06ZL, Data Sheet control and trigger circuit
[13] BLE, 2xZB1-10-3500-LWL, Data Sheet trigger unit
[14] BLE, ISR06, Data Sheet control circuit
[15] Schaffner, IT 258, Datasheet
[16] BLE, 2xZB1-10-6600-LWL, Data Sheet trigger unit
[17] Siebel Elektronik, current loop power supply system for SCR’s
[18] Saxogy Power Electronics, GD18008-T, product description