

Advantages in Application-Design by using Direct-Light-Triggered Thyristors

J. Przybilla¹, R. Keller¹, C. Schneider¹, H.-J. Schulze², F.-J. Niedernostheide²

¹eupec GmbH, Max-Planck-Str. 5, D-59581 Warstein, Germany

²Infineon AG, Balanstr. 59, D-81541 Munich, Germany

Abstract

In 1997, eupec manufactured his first direct-light-triggered 8kV thyristor with integrated protection functions. Since that time, eupec had sold more than 10000 LTTs in different sizes and with different blocking voltages. Direct-Light-Triggered Thyristors (LTT) have been developed for High Voltage Direct Current (HVDC) transmission applications because of the considerable advantage of high voltage blocking and the easy way of light triggering. Several protection functions were integrated in the LTT. Therefore that expensive and sensitive electronic components which are usually necessary for the external protection of electrically triggered thyristors (ETT) are dispensable.

LTTs are in use in applications with high voltage where a series connection of thyristors is required. Typical examples are HVDC installations, Static VAR Compensation (SVC), converters and soft starters for medium voltage drives and various pulse power applications. To show the performance of LTTs it is important to have a closer look at the system costs and the reliability.

In applications with high voltages and series connection, the LTT offers advantages because less electronics operating on high potential are required. This reduces the costs and improves the reliability of the system.

Thyristor Details

1) Direct-Light-Triggering & excess voltage Protection

The central area of the thyristor consists of a Break over Diode (BoD) and a four-stage Amplifying Gate (AG) structure (Fig. 1). The BoD is located inside the light-sensitive area. If the forward biased thyristor is illuminated by a short light pulse (typical duration = 10 μ s, light power \geq 40 mW, $\lambda =$ 900 -1000 nm), the generated electron-hole pairs are immediately separated in the space charge region of the p-n junction formed by the central parts of the p-base and the n-base. The whole current generated in this way provides the trigger current for the first AG. The

rest of the structure is fired by energy of the load circuit.

If an excess voltage pulse in forward direction is applied to the thyristor, the BoD provides a trigger current to turn the thyristor on. The curved shape of the p-n junction, which ensures that the electric field always has a maximum value at the BoD when a forward voltage is applied to the thyristor, achieves this. Thus, when the device voltage exceeds a certain threshold, avalanche generation starts in the BoD, providing a trigger current to turn on the thyristor safely by means of the AG structure.

Therefore it is guaranteed that the BoD is working over the whole positive temperature range, a wide range of dv/dt and with frequencies of 50Hz to 60Hz.

The blocking voltage of the BoD can be adjusted by the curvature of the central p-n junction and the distance between the BoD and the p-ring below the optical gate.

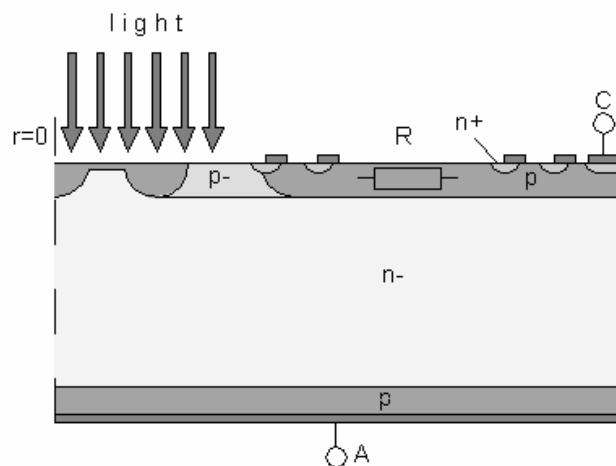


Fig. 1: Cross-section of center of Direct-Light-Triggering Thyristor

2) dv/dt Protection

Integration of a dv/dt protection function can be achieved by designing the ampyfing gate (AG) structure and the main cathode area such, that the innermost AG has higher dv/dt sensitivity than the other AGs and the main cathode area. This ensures that the thyristor is turned on safely by the AG structure when a voltage pulse with a dv/dt ramp exceeding the dv/dt capability of the innermost AG is applied to the thyristor. However, care has to be taken to fulfill the requirements concerning the light sensitivity and the dv/dt capability of the thyristor. Both features are mainly determined by the doping concentration of the p -base and the depth, width, and radial position of the n^+ -emitter, i.e. by the design of the innermost AG.

3) Forward Recovery Protection

eupec has shown in several tests that it is possible to integrate a forward-recovery protection into a LTT, too. Up to this time this protection function is not integrated to the standard LTT.

Commutation of a thyristor leads to an extraction of the free charge carriers in the n -base and the p -base and the formation of an anode-side depletion layer in the n -base. Since the depletion layer extends only to a certain depth into the n -base, excess carriers remain in its quasi-neutral plasma region, recombining there at a certain rate. When large regions of the thyristor have completely recovered and an uncontrolled forward voltage pulse appears, the remaining small region with excess carriers in the main cathode area may turn on. This may result in current filamentation, self-heating and, finally, in local destruction of the thyristor.

To avoid this, the thyristor should also be turned on in a controlled way by the AG structure if such a failure occurs. An integration of a corresponding protection function into the AG structure is not so easy, because the AGs usually turn off earlier than the main cathode area does. Consequently, the carrier concentration in the AG region is typically lower compared with the main cathode area. However, an increase of the carrier concentration in the AG region can be achieved by modifying the carrier's lifetime distribution so that it is lower in the main cathode area than in the AG structure [4,5,7-9]. This can be realized with relatively little effort by using a masked electron irradiation instead of the homogeneous one that is usually applied to adjust the on-state voltage.

Re-triggering of the thyristor by means of the AG structure in the case of forward voltage pulses during the forward recovery phase can be

further supported by phosphorus islands located inside the p^+ -emitter of the inner AGs (Fig. 2). The resulting anode-side n - p - n structures operate as local transistors when a reverse voltage is applied to the device. The doping concentration and the dimensions of the islands can control their carrier injection.

Thyristors designed in this way (i.e. provided with both non-homogeneous carrier lifetime distribution and local phosphorus islands) were subjected to extensive test measurements monitoring their response behavior on voltage pulses appearing during the forward recovery period. These test measurements demonstrated the effectiveness of the integrated forward recovery protection function [4, 5].

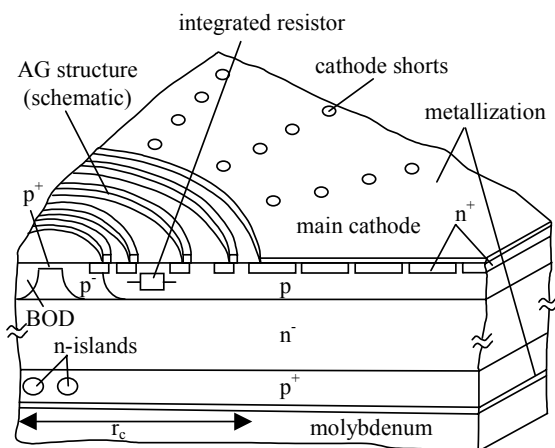


Fig. 2: Central part of the thyristor (BoD & four-stage AG structure) and part of the main cathode area (from Ref. [4]).

Advantages by using LTT

The differences between an ETT and LTT are the way of triggering and the internal protection functions of the LTT. To use a LTT it is only necessary to fix the light pipe into the housing (Fig. 3) and connect the light pipe to the laser diode.

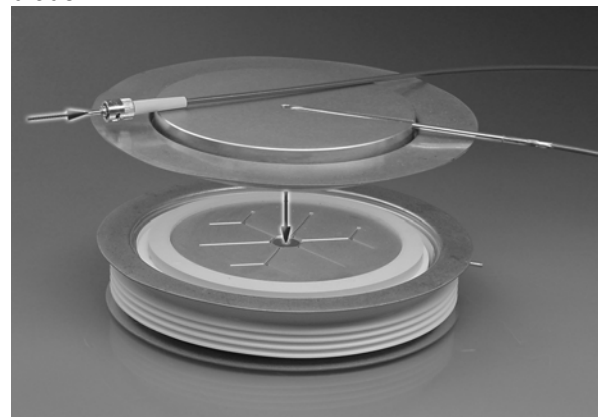


Fig. 3: LTT Housing with light pipe

The current pulse to the laser diode should be performed like shown in Fig 4. With this kind of trigger pulse the differences in gate delay time is minimized, which is important for parallel connection of LTT's.

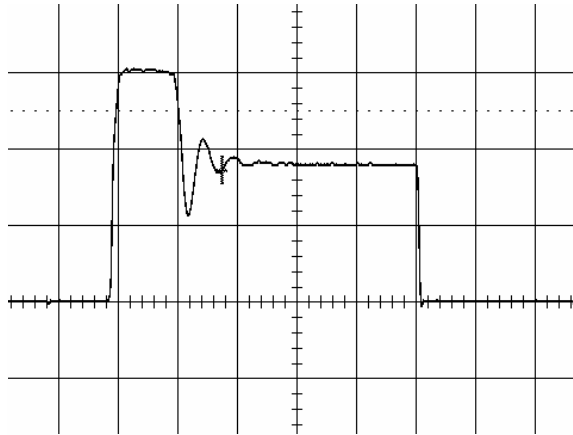


Fig. 4: Current-pulse of Laser diode, $x=2\mu\text{s}/\text{DIV}$, $y=0,5\text{A}/\text{DIV}$.

For high voltage applications normally several thyristors are connected in series. For this kind of application LTTs are a good choice, because of the easy way of triggering and the internal protection functions. The light-fiber performs the insulation between the main- and trigger circuits. No expensive pulse-transformers are needed.

For many high voltage applications electronics beside the thyristor ensure that the device is protected against too high voltage in forward direction, against too high raise of voltage in forward direction (dv/dt) and against positive voltage pulses during the recovery time (t_q). Because of the integration of the protection-functions BoD and dv/dt , the number of these electronic around the thyristor can be reduced. This increase the reliability of the system, because of less parts on high voltage potential in the application.

In applications where thyristors are connected antiparallel, like SVC, TPSC and medium voltage drives, it is possible to protect all devices against high voltage and high dv/dt in both directions by using the internal protection functions of the LTT. To ensure this protection the reverse blocking voltage must be higher than the BoD-voltage. Such a valve is working probably with less electronics beside the thyristors. This point reduce the costs and increase the reliability of the system

In applications where it is allowed to trigger the valve by the excess voltage it is possible to reduce the voltage-safety-factor.

The reduction of the voltage-safety-factor enables that the number of series connected devices can be reduced, and parts that are needed for a device like heat sinks, RC-snubbers and trigger units etc., too. The space that is needed for the valve is smaller, too.

In antiparallel-switched valves it is also possible to reduce the size of the RC-snubber by using LTTs. During the turn-off process the system inductances produce a negative voltage peak at the thyristor. This peak should normally not be higher than 80% of the max reverse blocking voltage. By using LTTs in antiparallel connection it is possible to increase this value of the maximum reverse blocking voltage because the BoD of the antiparallel thyristor protects the thyristor against destruction. In this thyristor the voltage pulse occurs as a voltage in forward direction. If the level is getting too high the LTT will be triggered by the BoD-protection and this protects both thyristors.

In special applications, for example in medium voltage soft starters for 4160V where it is not possible to reduce the number of thyristors in serial connection, it may be possible to avoid the use of snubber configurations completely.

Using eupec LTTs it is allowed to supply a gate pulse during the negative blocking period. This is not allowed at ETTs, because the gate-pulse produces a higher reverse blocking current. The losses generated by this current may destroy the device.

This advantage of the LTT could be used to reduce the number of trigger units in antiparallel connections of LTT's. The triggering laser diodes can be applied in series connection, so that all LTTs get the gate pulse at the same time.

By using LTTs it is possible to design redundant trigger systems. With optical splitter's it is easy to connect two or more trigger-units to one LTT, this is necessary for high reliable applications like HVDC and crowbars etc.

Applications for LTTs

A. High voltage direct current transmission (HVDC)

The development of LTTs with high blocking capability and integrated protection functions was driven by HVDC application (Fig. 5). To realize reliable thyristor valves for use in HVDC applications up to + - 500 kV it is necessary to connect a large number of thyristors in series and to protect these devices individually. When using LTTs instead of ETTs the external electronics circuit's components on high voltage potential for protection and triggering can be

omitted thus leading to an increase of the reliability of the system.

In HVDC applications there are different kinds of systems, for example Back-to-Back HVDC, Long Distance HVDC, Sea Cable HVDC.

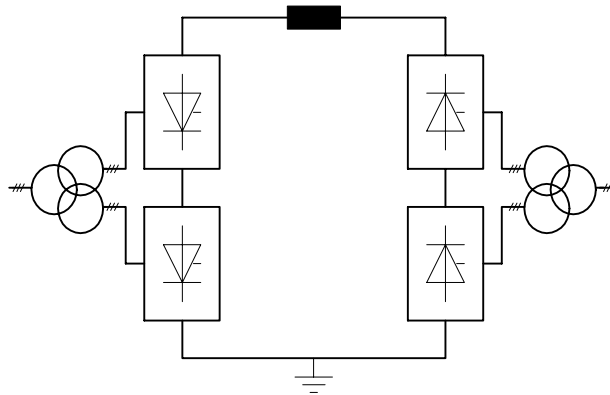


Fig. 5: Block circuit of an HVDC transmission

1) Back to Back HVDC systems

This kind of HVDC is used to connect two AC-systems with incompatible electrical parameters (Frequency, Voltage Level, and Short Circuit Power Level). The two converters are placed in the same building next to each other

2) Long Distance and Sea Cable HVDC systems

In Long Distance HVDC systems two AC systems are connected over a long distance of normally 300km to 1400km via a DC line. In normally power transfer in both directions is possible.

3) Sea Cable HVDC

In Sea Cable HVDC systems the two AC systems are connected via a special Sea Cable over distances from a few 10km up to 800km.

In these two applications often one system is the power-generating site and the other is the load site. The advantages of these systems are that there is no reactive power loading over the transmission line, that the power flow is totally controllable and that there is no contribution to short circuit power in existing AC networks.

In modern HVDC valves the light trigger pulse for the LTTs, that are installed in modular units (Fig. 6), is provided by three laser diodes, which are installed in the valve base electronics (VBE) on ground potential [10]. One of these three diodes is redundant, resulting in a two-out-of-three redundancy. These 3 diodes are connected to a multimode star coupler (MSC) with three inputs

and fourteen outputs. The MSC is an optical mixer, which distributes the in-coming light equally between the outgoing fibers. The outgoing light fibers are directly connected to the LTTs.

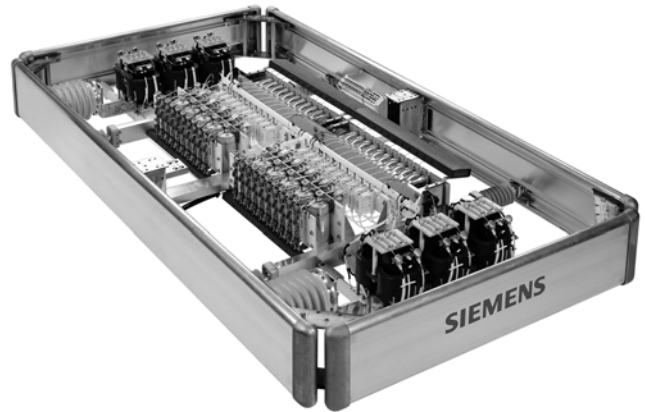


Fig. 6: Modern HVDC-Modular Unit with LTTs

B. Flexible AC Transmission Systems (FACTS)

1) Static VAR Compensation (SVC)

In SVC applications typically rated up to +250 MVar, 35 kV thyristor valves are used to connect capacitors or inductors to an AC grid to compensate reactive power (Fig. 7). Thus the thyristor valve has to consist of high voltage AC switches resulting in series and antiparallel connection of devices. SVCs increase the reliability and availability of transmission systems (e.g. counteract excess voltage after a major load rejection and avoid line tripping). Also they increase the dynamic and transient grid stability and the quality of supplies for sensitive industries [10].

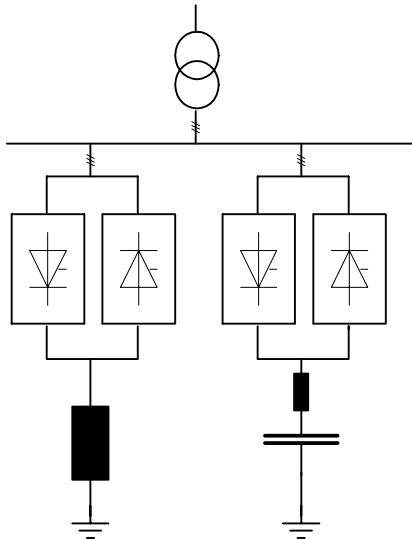


Fig. 7: Block circuit of SVC configurations

C. Medium voltage drives (MV)

Existing MV drive products have a range of 2.3 to 7.2 kV, which tend to higher voltage up to 15 kV. The main drives are mostly realized with IGBT modules in two or more level inverters. For the high end in voltage and power, Press Pack IGBT's, GCT's and even LTTs (frequencies 50Hz to 110Hz) may be of interest because direct series connection with redundancy of more than two semiconductors can be realized in one-level inverters.

In soft starters which work with line commutated thyristors can be used. In the upper voltage region where series connection's of semiconductors are necessary, the use of smaller LTTs (eupec T553N) is advantageous.

D. Pulse power applications

Because of the high di/dt-capability, LTTs can be used in many pulse power applications. These applications are for example magnetic deformation, crowbars and so on.

At pulse power applications the energy is normally stored in capacitors, which are discharged in one or several pulses with high di/dt and current.

1) Magnetic Deformation

At magnetic deformation applications normally a capacitor is charged to several kilovolts (Fig 8), then the laser pulse triggers the LTT. The capacitor is discharged to a special air coil. A crow bar diode protects the capacitor against negative charging. In the special air coil there is the object, which is supposed to be deformed. The object can be two pipes for example which

are to be fixed together. This kind of magnetic deformation offers many advantages.

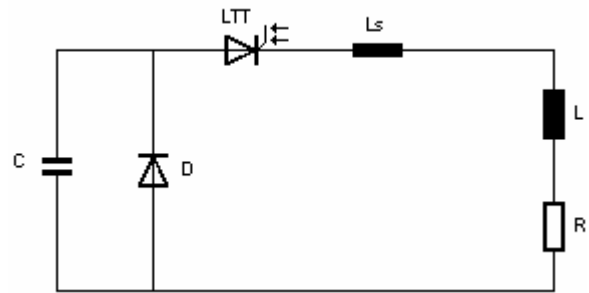


Fig. 8: Schematic for magnetic deformation circuit

LTTs are tested in this application with charging voltage up to 5 kV, load di/dt of 5 kA/us and a maximum load current of 35 kA.

2) Crow Bar Applications

In Crow bar applications, LTTs are used to protect sensitive and expensive components like klystrons or high power capacitors. The LTTs are switched directly in parallel to the part that should be protected (Fig. 9). In case of any failures or irregular functions, the LTTs are triggered by laser pulse and the current commutates to the thyristors. In case of excess voltage or high dv/dt in the system, the internal protection function triggers the LTT and the expensive parts are protected.

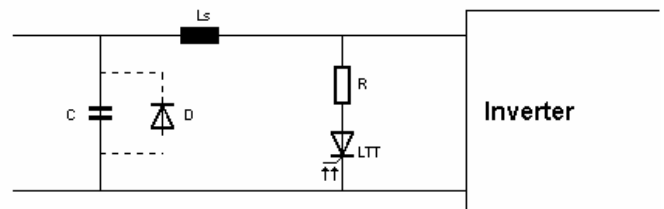


Fig. 9: Simplified schematic for a crow bar circuit

LTTs are tested in this application with charging voltage of 65 kV and di/dt of about 5 kA/us.

3) Replacement of Ignitrons

In several existing applications ignitrons are in use. These devices will be replaced because of the pollution that can be caused by mercury. LTTs are a solution for most of these applications.

eupec delivered stacks for a power transfer system single pulses 80 kA sine half waves 700µs and crowbar 80 kA, 25ms rectangular.

Outlook

1) High blocking thyristors

eupec develops thyristors and diodes with 13 kV blocking capability for HVDC and pulsed power

application. First types are 4" pellet sized semiconductors; engineering samples will be available in the middle of 2004. The underlying concept is an asymmetric thyristor and a rectifier diode. This devices can be used single, or in serial connection in one housing. (Fig. 10.)

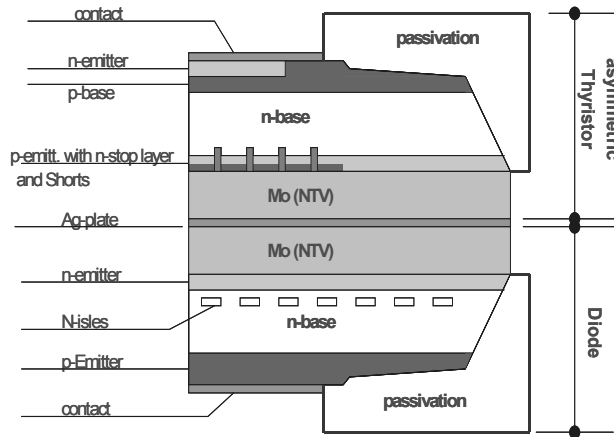


Fig.10: mechanical pellet construction of a symmetric device

2) Rise of di/dt and single pulse current capability of LTT's
 di/dt at the beginning of pulses and surge current capability for short pulses depends on design of the AG structure of LTT's. eupec performance investigations to rise both values from now 5 kA/μs for pulse power thyristors to higher values. (Fig. 11)

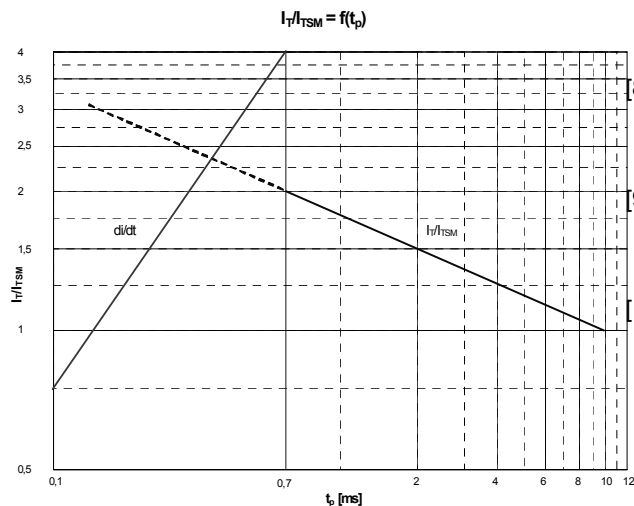


Fig. 11: Principle of limiting parameters of surge capability

Summary

In conclusion, we point out that by using light-triggered thyristors combined with self-protection functions costs of many applications could be reduced and the reliability will be increased.

Acknowledgments

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