Abstract Number #10067

Direct Light-Triggered Solid-State Switches For Pulsed Power Applications

J. Przybilla[1], R. Keller[1], U. Kellner[1], H.-J. Schulze[2], F.-J. Niedernostheide[2], T. Peppel[3]
[1]eupec GmbH, Max-Plank-Str. 5, 59581 Warstein, Germany
[2]Infineon AG, Balanstr. 59, D-81541 Munich, Germany
[3]M&P GmbH, Bismarckstr. 75, D-02111 Dresden Germany

Abstract

For pulsed power applications solid-state switches are required. Because of their easy series connection in stack assemblies and the reliable way of triggering direct light-triggered thyristors should be preferred as solid-state switches. Furthermore, such high-power light-triggered thyristors enable the integration of protection functions like, e.g., overvoltage protection and dv/dt protection.

I. DESIGN OF LTTs

Direct Light-Triggered Thyristors (LTTs) are well known since the 1960s. At the beginning of this development the main problem was the availability of a powerful and cheap light source for triggering. Because of the demand for a powerful and cheap light source for communication, suitable laser diodes became available. In 1995, eupec developed a 4-inch 8 kV direct light-triggered thyristor suitable for solid state switches. Because of the target market of High Voltage Direct Current transmission (HVDC), the LTTs are provided with overvoltage and dv/dt protection functions, both directly integrated into the thyristor. The thyristors are fabricated like electrically-triggered thyristors (ETTs) by well-established technologies. The only difference between ETTs and LTTs is the light sensitive gate area containing the integrated protection functions in the center of the thyristor (Fig. 1).

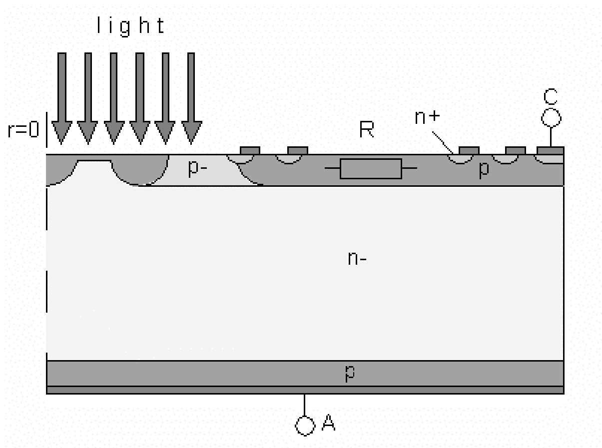

Figure 1. Cross-section of the center of the light-triggered thyristor with integrated protection functions

Triggering of an LTT is achieved by a 40mW light pulse generated from a laser diode. The wavelength of the emitted light should be between 850 and 1000nm. Typical pulse durations are about 10 µs. The light pulse is transmitted by a special light guide to the light sensitive area of the LTT.

The central area of the LTT consists of a Breakover Diode (BoD) and a multiple Amplifying Gate (AG) structure. The BoD is located inside the light-sensitive area. If the forward voltage exceeds the breakdown voltage of the BoD, the resulting avalanche current of the BoD triggers the LTT. Turn-on is supported by the multiple AG structure. The BoD structure is designed to trigger the LTT with 50Hz (60Hz) over a wide temperature and di/dt range. The integrated dv/dt protection is achieved by adjusting the dv/dt sensitivity at the innermost AG. Therefore, in case of a voltage pulse with a high dv/dt the resulting displacement current triggers the LTT and the thyristor turns on in a safe way due to the good current spread supported by the AG structure. The reliability of this protection function has been tested over a wide dv/dt and temperature range.

By integrating a resistor into the AG structure (Fig. 1) it is possible to raise the di/dt capability significantly by controlling the rate of current increase. Tests have shown that LTTs with such an internal resistor can handle di/dt´s up to 10kA/µs for single pulse operation and 5kA/µs for periodical operation (60Hz).

II. LTT STACK ASSEMBLY AND TRIGGER UNITS

A. LTTs for Pulsed Power Applications

eupec has developed four different types of LTTs and one special diode for pulsed power applications (Tab. 1). All LTTs are symmetrically-blocking light-triggered thyristors with BoD- and dv/dt protection. Up to now, eupec has produced more than 5000 LTTs; most of them are used for HVDC transmission applications, Static Var Converters (SVCs), soft-starter and pulsed power applications.

Table 1. eupec product spectrum for pulsed power applications

Type	Blocking Voltage	BoD Voltage	Size (Pellet)	surge current tp=700µs
T1503NH	8kV	7.5kV	4 inch	90kA
T2563NH	8kV	7.5kV	5 inch	126kA
T4003NH	5.2kV	5.2kV	5 inch	210kA
D2601NH	9kV	-------	3 inch	104kA
T553N[1)]	7kV	6.5kV	2 inch	24kA

[1)]for further information see section IV

B. Stacks for LTTs

Together with our customers, we have developed a special kind of stack-assembly for high-voltage series connection of LTTs. In this stack (Fig. 2) 14 LTTs are connected in series (2 times 7 LTTs). A resistor is connected in parallel to each LTT in order to ensure equal voltage sharing of the total voltage applied to the stack assembly. The thread rods are made of carbon fibers and special care has been taken to avoid sharp edges because at such edges a large electric field strength can arise. In this application the trigger unit is installed at the bottom of the stack.

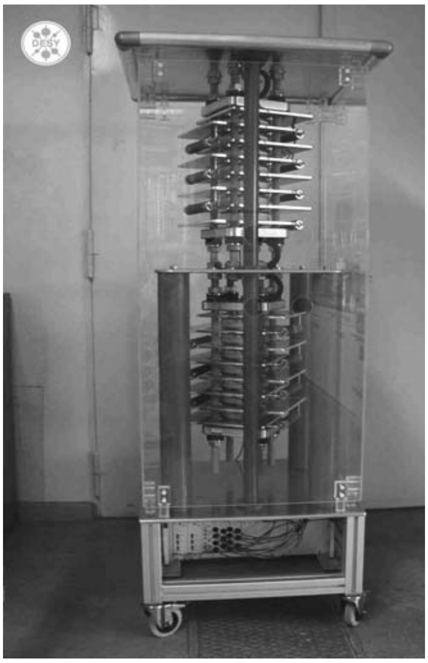

Figure 2. Stack assembly with LTTs

C. Triggering of LTTs

LTTs are used in a wide range of applications and in different environments. This requires an adapted behavior of the triggering unit. For cable analyzing, for example, the equipment is entirely located in a car with a very short distance between control system, LTT-driver and LTT. In other applications the distance between the components of the plant are larger.

In certain applications with a low di/dt, picket fence pulses (Fig. 4) are required. This is different from most of the pulse power applications, where a single pulse is sufficient.

Because of the various requirements a very flexible LTT-driver, LFTD18 (Light Fired Thyristor Driver), was developed. For user friendly handling, all of the required functions for safe triggering are integrated into the LFTD18. The LFTD18 is not only capable of triggering a single LTT, but also up to 18 LTTs simultaneously. Fig.3 shows the structure of the driver

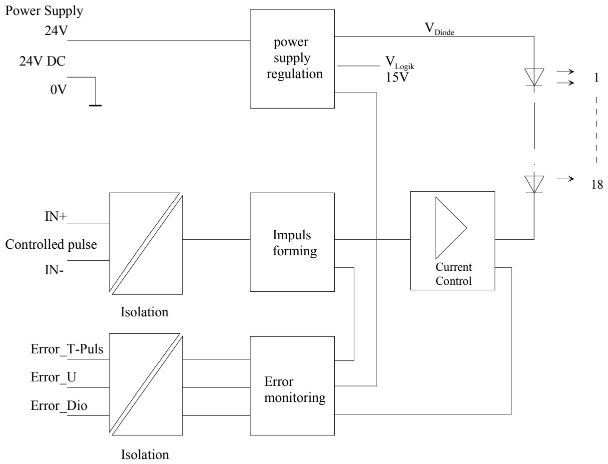

Figure 3. Block Diagram of the LFTD18

1) Generation of the signal and the triggering pulse

The control system must generate a pulse with a minimum pulse duration of 20 µs to trigger the LFTD18. The LFTD18 offers two ways for triggering: by a light pulse or by an electrical pulse. For light triggering, the driver converts the input pulse to a light pulse (or pulses) of 40mW.

The interface of an HP/Agilent versatile fiber module HFBR1528/HFBR2828 is used to couple the light pulse into the fiber optic. For safety reasons, a second optical receiver can be mounted for an additional input signal. In this case, both input channels are connected via an optical OR-gate (Fig. 3, left).

For electrical triggering an opto-coupler is used (Fig. 4, right). The input circuit shapes the input pulse. Depending on the application, this input pulse is converted either into a single 10µs output pulse or into picket fence output pulses with a frequency of 6kHz (Fig. 5).

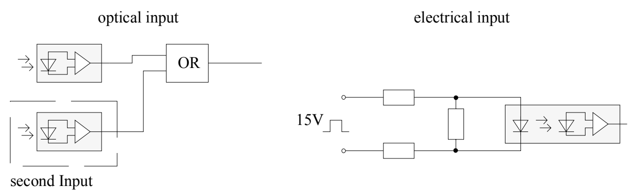

Figure 4. Triggering of the LFTD18

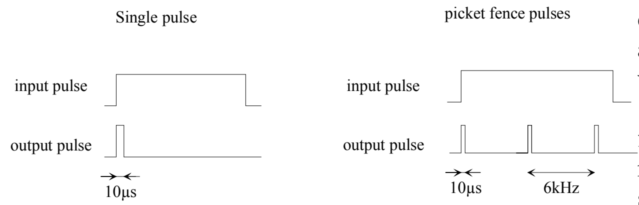

Figure 5. Two types of pulses used for pulsed power applications

As already mentioned, a light pulse of 40mW is required for safe triggering of the LTTs in the whole operating range. For a current amplitude of 0.9A, the length of the electrical pulse controlling the laser diode should not exceed 10µs. Otherwise, the power dissipation in the laser diode is too high. For faster turning-on of the LTTs, a higher current during the first 2µs of the pulse is recommended (steeple pulse Fig. 6). For applications that are not time-critical, a steeple pulse is not required, for parallel switching of LTTs the steeple pulse should be used.

The set point together with the feed forward at the input of the current controller forces a higher current through the laser diode. Because of the high current the laser diode reaches the required light power faster to trigger the LTT.

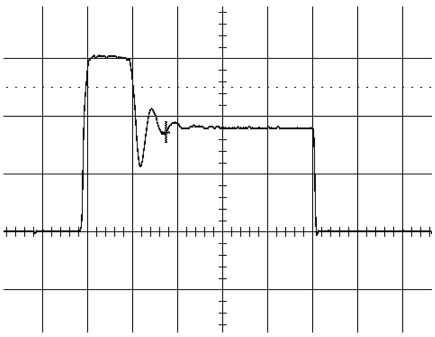

Figure 6. Steeple pulse

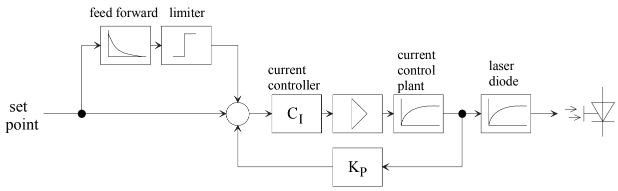

Figure 7. Current control of the laser diodes

2) Monitoring of the LFTD18

The reasons for monitoring the LFTD18 signals are to ensure a save triggering of the thyristor, a long lifetime of the arrangement driver-thyristor and a high reliability over the entire life cycle. However, it is also possible to trigger the thyristor safely by a driver without built-in control. Incorrect driving of the laser diode reduces the expected lifetime. On the other hand, it is very important in many cases that the driver and the thyristor continue operation even if an error message appears. Therefore, most errors are messages to the control system, but the driver is still working.

All errors will be locked. After checking the correct function of the driver a reset pulse cancels the error messages. The reset pulse is generated from the control system (only electrical pulse) or from the driver itself (auto-reset).

3) Under voltage error and lockout

The internal voltages and the 24 V supply voltage are also monitored. If a voltage error occurs, the driver sends an error message to the control system and tries to stop all processes. If the voltage further reduces, the output pulses of the driver are disabled, because safe driving of the thyristor cannot be guaranteed in this case.

4) Pulse error

Moreover, the correct conversion of the electrical input pulses to 10µs output pulses by the LFTD18 is supervised by the monitoring unit in order to limit the power dissipation in the laser diode. Too long output pulses or a too high repetition rate of the input pulses generate an error message (Fig. 8).

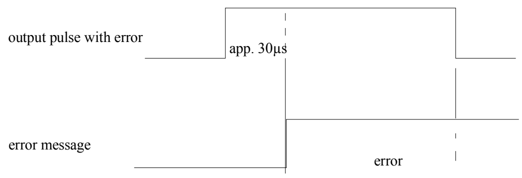

Figure 8. Time behavior of the pulse error

5) Diode error

The diode error combines two errors: The first is related to a current control error of the LFTD18. It appears when the LFTD18 is out of order or the control reserve is too small. The second error message is generated, if a laser diode is short-circuited. This is controlled by monitoring the voltage drop across the laser diode (Fig. 8).

In the standard configuration the output pulse is usually not automatically disabled when an error message appears—except for the "under voltage error". However, disabling of the output pulse is possible (on request). Further, all error signals can be combined to an optical error signal (HP/Agilent Transmitter HFBR2815, on request).

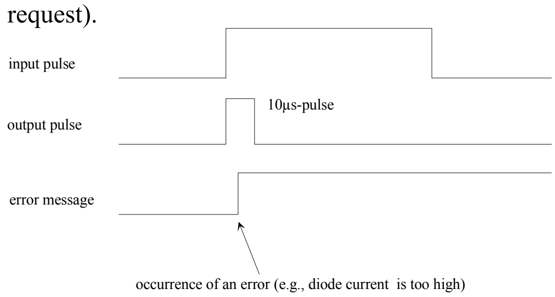

Figure 9. Time behavior of the diode error

III. PULSED POWER APPLICATION

A. Application Overview

Figure 10 illustrates the variety of pulsed power applications. Pulse durations range from several tenths of microseconds up to hundred milliseconds. The pulse energy covers a broad energy interval, ranging from 1Ws for laser applications up to MWs for crowbar applications. In the following we focus on the applications, for which LTTs are useful and list several examples of projects accomplished by eupec.

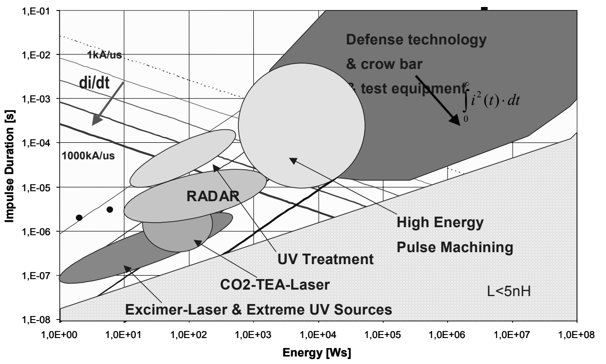

Figure 10. Pulsed power applications

B. Crowbars

Crowbars are used to protect expensive equipment against fault conditions.

Accomplished projects:

- a 55kV DC / 5kA/µs crowbar, consisting of 14 serially-connected LTTs of type T1503NH75TS02 to protect klystrons in a transmitter power supply at DESY Hamburg (Germany, cf. also Fig. 2)
- two 130kV DC / 5kA crowbars, consisting of 52 serially-connected LTTs of type T553N70TOH (Spain)
- four 35 kV / 80 kA crowbars, consisting of 6 LTTs T2563N75TS01 in serial connection with 2 stacks in parallel (Italy)

C. Power Transfer System (PTST)

Accomplished project:

- four PTST (35kV, 80kA, 200A/µs, 700µs) consisting of 6 serially-connected LTTs of type T2563N75TS01, 2 stacks in parallel (Italy)

D. Cable Analysis Systems

Cable analysis systems are based on a mobile oscillating wave test system (up to 250kV) for measurement and location of partial discharge in high-voltage-cable networks (Fig. 11).

Accomplished projects:

- cable analysis system, consisting of 40 serially-connected LTTs of type T553N70TOH; to each thyristor a diode of type D711N68T is antiparallel-connected (Switzerland)
- mobile cable analysis system (60 kV), consisting of 18 serially-connected LTTs of type T553N70TOH (Germany)

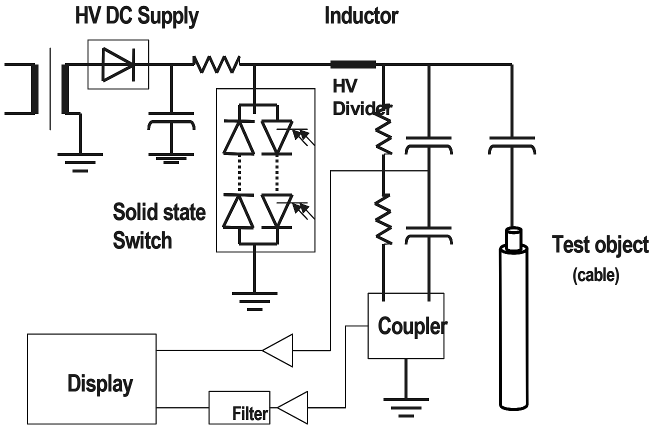

Figure 11. Schematic of cable analysis system

E. Fast Magnetic Forming

Fast magnetic forming can be used to connect two or more tubes, pipes etc. The advantage of this technique is its high repetition rate and the high quality of the final compound.

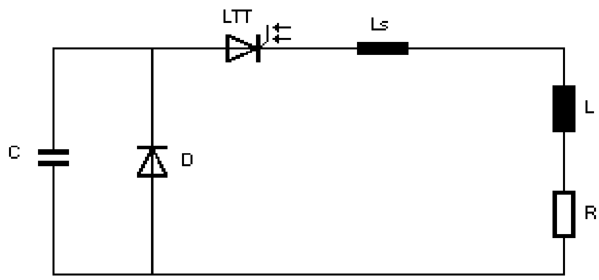

Figure 12. Schematic of magnetic forming

Accomplished project:

- a fast magnetic forming system (6kV, 35kA, 5kA/µs), consisting of LTTs of type T1503NH75TOH (Germany)

IV. OUTLOOK

A. 13kV LTT

eupec is working on the development of 13 kV direct light-triggered asymmetric thyristors. By connecting such a thyristor in series with a 13 kV diode and installing both devices in a single press-pack housing, a symmetrically-blocking 13 kV thyristor can be easily created. Theoretical and experimental investigations have shown that this combination produces lower power losses than one symmetrically-blocking device for operating conditions typically used in HVDC applications. The first samples of 13kV electrically triggered thyristors are under test.

B. Increasing the di/dt capability

The target value for the di/dt capability of LTTs for pulse power applications is 15kA/µs for a maximum current up to 100kA. To reach this target value, further studies concerning the turn-on behavior of LTTs are in progress.

C. 2 inch LTTs with higher di/dt capability

On the basis of the T553N70TOH eupec will develop a 2-inch LTT with higher di/dt capability. This kind of LTT can be used in applications with high di/dt and maximum currents of up to 10kA. Typical examples are laser applications.

D. 38mm LTT

For applications with maximum currents of up to 4 kA eupec will develop a small LTT with a pellet diameter of 38mm and 7kV blocking capability. This kind of device can be used in applications such as laser triggering etc.

E. New methods for driver-monitoring

Currently, only the electrical properties are monitored. By mounting the receiver diode and the transmitter diode in a single case, it is also possible to monitor the optical properties of the laser diode. An accurate analysis of the light intensity allows the detection of changes in the optical properties of the diode, e.g., change in light intensity, coupling to the light pipe etc.

For safety applications, a permanent monitoring of the driver is required, e.g., in crowbar applications. To accomplish this requirement, the laser diodes are monitored in the off state. With ultra short pulses the driver analizes the status of the laser diodes without turning on the LTT.

F. Support for new designs and development

To minimize the time-to-market cycle, eupec and M&P offer evaluation-kits based on the LFTD18 with optical input. An evaluation-kit (Fig. 9) consists of an LFTD18 and an HFBR1528-transmitter-board to trigger the LFTD18. The input signal of the HFBR1528-transmitter-board requires 0V for triggering the LFTD18. Triggering with a micro-controller-board or—as simple version—triggering with a push button is possible.

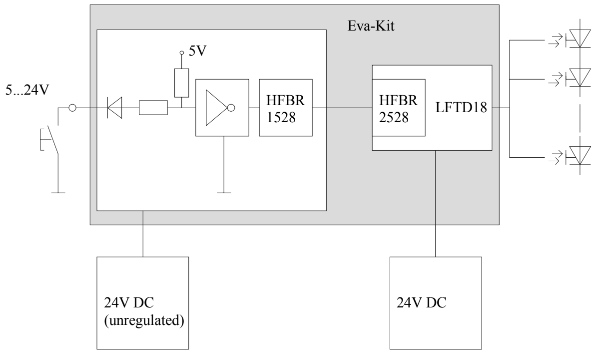

Figure 13. Evaluation-kit

V. ACKNOWLEDGMENT

We would like to thank C. Schneider, T. Luse and O. Herlitius for experimental support.

VI. References

1. J. Dorn, U. Kellner, F.-J. Niedernostheide, H.-J. Schulze, "State of the Art Light Triggered Thyristors with Integrated Protection Functions". Power Electronics Europe, Issue2 2002, pp29-35
2. F.-J. Niedernostheide, H.-J. Schulze, U. Kellner-Werdehausen, "Self-Protected High Power Thyristors" PCIM 2001, Power Conversion (Nürnberg, Germany), p. 51-56
3. A. Henselek "Maschinenkonzepte für die industrielle Anwendung von Elektromagnetischer Umformung" Kolloquium Elektromagnetische Umformung 15.05.2001 p. 39-44