

New Methods in Teaching of Power Electronics Converters and Devices*

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In this paper traditional and state-of-the-art educational methods and experience in teaching power electronic converters and power electronic devices to undergraduate students are described. The main focus is on ways of improving study using e-learning methods. Interactive screens with animations created for illustrating the features of power converters and devices are presented.

Keywords: E-Learning; power electronics converter; power semiconductor devices

INTRODUCTION

GOOD UNDERSTANDING of the performance of power semiconductor devices offers a sound basis for developing power semiconductor converters, including their design and measurement. Many books [1, 2, 6] can give students the basic requisite ideas, providing excellent support for laboratory experiments and projects. One way of supporting power electronics lecture courses and encouraging interest in power electronics is a project-oriented power electronics educational laboratory [3] and virtual laboratories [9, 11–16]. Another form of learning that complements and supplements the lecture course is simulating power electronics devices using various simulation programmes such as Saber, PSpice, Caspoc, etc. [5]. There are also learning methods that combine simulation results and animations on the same screen [4, 7, 8]. The e-learning materials presented in this paper were originally and primarily designed for teachers, to be used during traditional lectures. However, it was found that these e-learning materials could equally well be used for self-study purposes, as long as good instructions and clear assignments are provided. Consequently, these materials are now recommended for self-study, especially for students who have passed at least a basic course in power electronics and devices.

ACTUAL STATUS IN TEACHING OF POWER ELECTRONICS CONVERTERS AND DEVICES

First-time students are acquainted with power semiconductor devices in the third-year summer

semester under the subject ‘Power Electronics’, comprising three hours of lectures and three hours of exercises weekly. This is the basic subject in the Electrical Drives section and is an obligatory course. Apart from an introductory section, lectures in this subject start with a description of the properties and parameters of individual non-controlled and controlled semiconductor devices (diode, SCR, triac, GTO, IGCT, BJT, MOSFET, IGBT, MCT, SITH, SIT). The theory of power semiconductor devices is explained as an introduction to the basic course of power electronics. Lectures as well as exercises in power electronics subjects are already well established. The exercises start with topology analysis and synthesis of a given converter at distinct intervals in its operation, during which the status of any semiconductor device is not changed. The equivalent circuit of the converter for a given interval can then be linearized and thus described by linear differential equations. The connecting quantities between individual discrete intervals are energy storage elements; these values cannot be changed immediately (e.g. capacitor voltage and inductor current). The ideal semiconductor device is usually assumed at the point of analysis of the converter operation, which is sufficient for the given purpose.

E-LEARNING IN TEACHING OF THE CONVERTER TOPOLOGIES

When studying a specific power electronic circuit, the first thing the student needs to know is the different current paths depending on the switching states and certain currents and voltages. With traditional teaching methods the current paths are drawn in a figure of the power circuit using different colours, or the teacher presents

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them in a slide-show in the classroom. This is where the use of interactive animations is introduced, as illustrated in the following examples. The animations were created in the programme Macro-media Director.

The square wave principle is a basic switching strategy used for high-power converters. The voltage source inverter (Fig. 1) using square wave switching operates with switches alternately switching in a phase leg with 180 degrees conduction. Two interactive screens are shown for illustration. The first time function shows the status of the switches (1–6, on/off), the second one shows the potential of phase A to neutral point N (U_{AN}) and phase B to the neutral point N (U_{BN}). The fourth one shows the potential of phase A to neutral point n (U_{An}) and the fifth time function shows phase B to the neutral point n (U_{Bn}). The last time function shows the line to line voltage (U_{AB}). The switches are always in the position corresponding to the position of the temporal ledge. The input voltage U_d is usually controllable.

The square wave is also obtained for sufficiently large values of the modulation index, because the PWM degenerates into square wave operation. Therefore, at any given time, three switches are on.

The multilevel converter is used for high-power application. In Fig. 2, animation of one leg of the multilevel converter is shown. The other two legs (not shown) would be connected across the same DC bus-bar. The topology appears to double the number of semiconductors. However, doubling the number of semiconductors with the same voltage rating would double the dc voltage and the power capacity of the converter.

The converter operation is explained in the animation. With a change in the conduction angle, the output voltage level is varied with fast response. The line voltage with the steps resembles a sinusoidal voltage. In practice, multilevel converters with more levels (5, 7, 9) are utilized, bringing the voltage shape even closer to a sinusoidal voltage. The animation in Fig. 2 shows the current path (dotted line) of a three-level converter in the

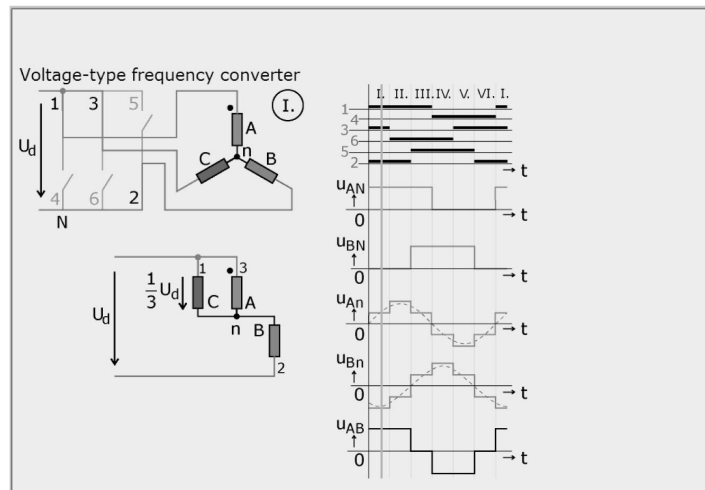


Fig. 1. Square wave switching.

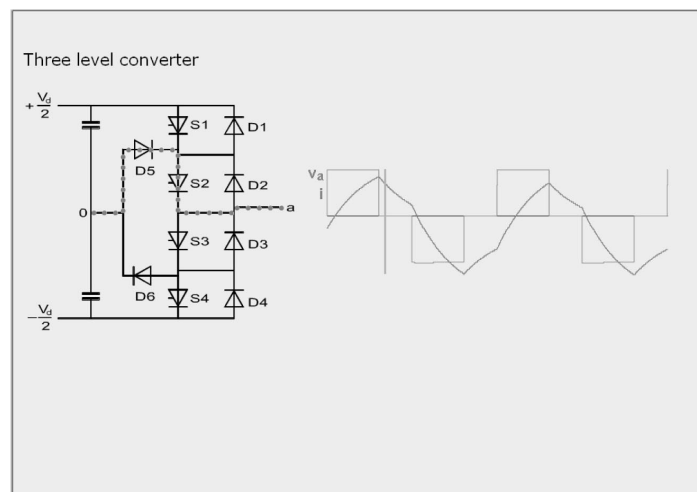


Fig. 2. Multilevel converter.

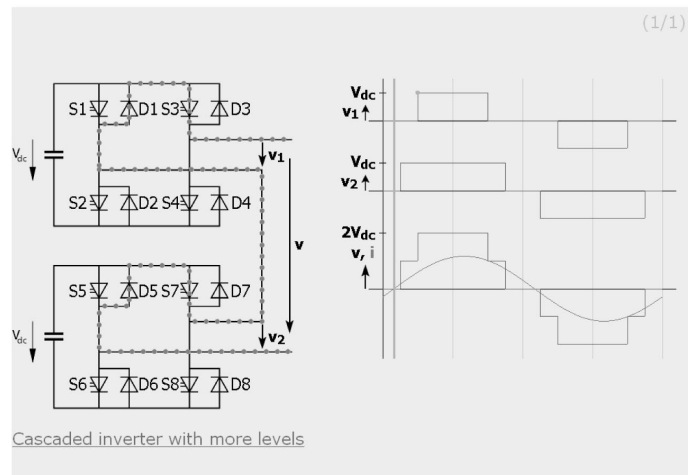


Fig. 3. Cascaded inverter (chain converter).

interval of zero output voltage. With the slide of the temporal ledge, the current path for the other two voltage levels is shown. The waveform shown in Fig. 2 is a square wave obtained by closing the devices S1 and S2 for 180 degrees or less and closing S3 and S4 again for 180 degrees or less. The zero voltage level of the first waveform in Fig. 2 is obtained by turning S1 off and S3 on earlier. This, in combination with the diode D5 and D6, clamps the phase voltage to zero with respect to a midpoint 0. This feature allows us to obtain the variable phase angle and rms line voltage.

In the same way, other typical high-power converter configurations such as a chain converter and a twelve pulse converter scheme are shown and their operation is explained in the animation package.

In the cascaded inverter or so-called 'chain circuit' approach, each pole is composed of a number of complete single-phase, voltage-sourced 'H-bridge' converters, each with its own isolated DC capacitor, as illustrated in Fig. 3.

One of the multilevel converter topologies incorporates cascaded single-phase H-bridges with separate dc sources. Fig. 3 shows a single-phase structure of an m -level cascade inverter ($m = 5$). The dc source is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs, $+U_{DC}$, 0, and $-U_{DC}$ by connecting the dc source to the ac output using different combinations of the four switches: S_1 , S_2 , S_3 and S_4 . To obtain $+U_{DC}$, switches S_3 and S_2 are turned on. Turning on the switches S_1 and S_4 yields voltage $-U_{DC}$. If S_1 and S_3 or S_2 and S_4 are turned on, the output voltage is 0. The conduction angle of the first pulse can be changed by moving the orange dot.

The ac outputs of each of the different full-bridge inverter levels are connected in a series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels m in a cascade inverter is defined by $m = 2s+1$, where s is the number of separate dc sources. Fig. 3 shows a 5-level example,

although 11- or 13-level converters are usually built. The conducting angles of each H-bridge, $\theta_1, \theta_2, \dots, \theta_s$, can be chosen such that the voltage total harmonic distortion is at a minimum. Normally, these angles are chosen so as to cancel the predominant lower frequency harmonics (the 5th, 7th, 11th, and 13th harmonics can be eliminated with the appropriate conducting angles for an 11-level case chain converter). One degree of freedom is used, so that the magnitude of the fundamental waveform corresponds to the reference waveform's amplitude or modulation index.

The chain circuit represents a straightforward approach to the realization of a multilevel converter for use in high-power applications without the need for magnetic-combining circuitry and complex transformer arrangements. The main advantage of this approach is the well-defined operating environment for each three-level pole within a substantially isolated H-bridge circuit. The number of H-bridges in a series is not limited by factors such as the escalating voltage rating of the top diodes required for other types of multilevel circuits. This allows high-power ratings to be achieved without magnetic-combining circuits. With this configuration, each DC capacitor needs to be rated for the large, predominantly second harmonic, ripple current, which can readily provide single-phase compensation when system conditions so require. The chain circuit, as well as other multilevel circuits, can be designed to produce a quasi-harmonic neutralized waveform by simply selecting the appropriate angles for a_1, a_2, \dots, a_n , depending on the pulse number required. This is achieved without the need for magnetic-combining circuits and complicated converter transformer winding configurations.

However, this is no match for the design of the converter, therefore we need to be sure of the specific facilities and parameters for individual semiconductor devices. As power semiconductor devices belong to the basic structural elements of converters, their correct selection and design can

markedly influence the facilities and parameters of the whole converter.

Solid knowledge of power semiconductor devices permits the student to determine to what extent it is possible to idealize the individual parameters of such devices. Lectures in this area are traditional, and blackboard and slides are usually used to aid explanation. The lectures are usually given ahead of the associated exercises, in order that the students are already familiar with the topic before they are required to practise it.

The exercises are divided into three-week cycles. In the first week of the cycle there is a calculation exercise, where typical examples are calculated. The examples calculated are related to the measurements that follow in the next two weeks. The maximum number of students in the group undertaking measurement exercises is ten. The group is also divided into two subgroups, measuring various tasks according to the curriculum. All basic types of converters are included in the exercises. The majority of laboratory models for exercises in Power Electronics were developed by the department. The substantial share of these models involved our students, either under the framework of semestral projects or for diploma theses. The majority of the laboratory models are of modular construction with the possibility to create various types of converters. Students work on their own, according to specific tasks in measurement propositions.

There are models for measuring the static and dynamic properties of power semiconductor devices such as thyristor, triac, bipolar junction transistor, MOSFET and IGBT. The limited time is the reason why mainly the switching properties of MOSFET and IGBT and their influence are measured.

In all the eligible subjects in the field of Power Electronics (power semiconductor converters, power semiconductor converters applications, control circuits for power electronics, applied software in electrical engineering), students deal with evaluation of switching losses and methods of reduction, protection against over current and over voltage as well as various types of drivers for semiconductor devices.

Simulations using the programme PSpice are also used for verification of properties of power semiconductor devices. For this subject, the students are divided into small subgroups of two or three and each subgroup is given a task to solve. The solution usually takes the following form. First the design is completed and the required values are calculated. This is followed by verification by simulation programme and afterwards practical measurement of the laboratory model of the switch or converter is done. An important element is evaluation of the results obtained. The subgroup defends their solution in front of the other subgroups. The whole group acts as opponent and evaluator of the subgroup's work.

E-LEARNING IN TEACHING OF POWER SEMICONDUCTOR DEVICES

The rapid development of power electronics has brought such a large amount of new knowledge into the field that it is difficult to stay on top, particularly given the usual time constraints. Apart from omitting the less relevant elements in the subject, one method of speeding up the process of acquiring new information and simultaneously making it more attractive is using the new system of teaching known as 'e-learning'.

E-learning is a new education concept with a facility for rapid development. Its expansion through the internet using multimedia ensures easy access for a wide range of interested people. However, there are many visions of how such educational material will actually look and what purpose it will eventually serve.

The interactive module itself should have main screens assigned for lectures and sub-screens assigned for self-study. The main screens should comprise only the more substantial parts of the subject: the principal schemes and diagrams, substantial terms, brief information, basic equations, animations and interactive screens. All text and pictures should be large and easily distinguished. The main screen can be static, where the problem is explained by the traditional method (Fig. 4), or animated, where individual facilities and functions are presented in a visual form (Figs. 5 to 7).

Sub-screens carry detailed information about the problem and are available by clicking on the cross-reference icons on the main screen. In principle, they have a similar structure to what one would expect to find in textbooks (Fig. 8).

When creating the animations for the power semiconductor devices we especially focused on their static and dynamic qualities. The basic structure of the power semiconductor devices and equivalent circuits are made as static screens presented in the classic style (Fig. 4).

It is possible to enter parameters and instructions and observe changes and actions in the demo scheme as well as operating point movement in the current voltage or in the area of safe operating (Fig. 5) when presenting the static properties of the power semiconductor devices. To illustrate this, some main screens are presented here. Figs. 5a and 5b present the static current-voltage characteristic of the thyristor. The working point of the thyristor could be in the forward blocking state (Fig. 5a). When the gate current is applied by clicking the mouse, the thyristor starts to conduct anode current and the working point is transferred to the forward on-state characteristic (Fig. 5b). After the conduction is established, the gate signal is no longer required to maintain the anode current. Load resistor R , which can be changed using the mouse, determines the value of the anode current.

Figs. 6a, 6b and 6c show the turn-on properties of the thyristor. The thyristor must be in a forward

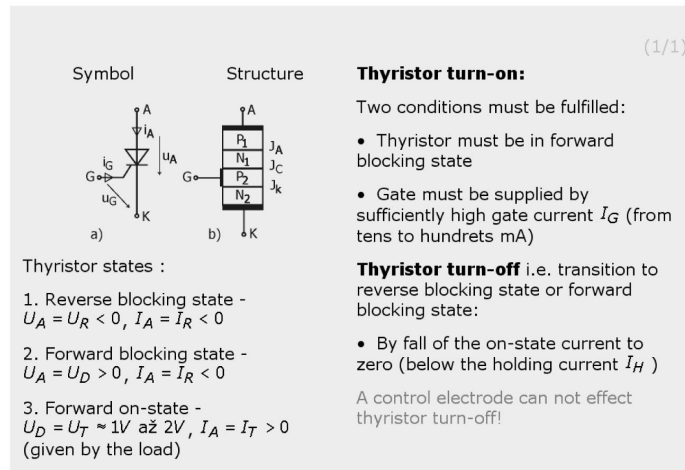
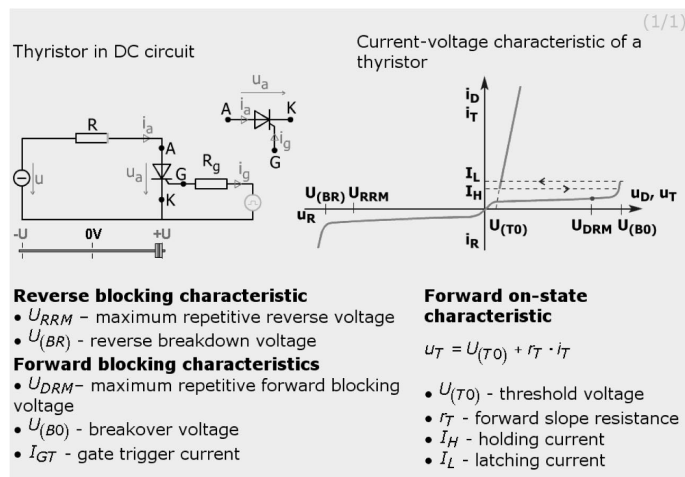


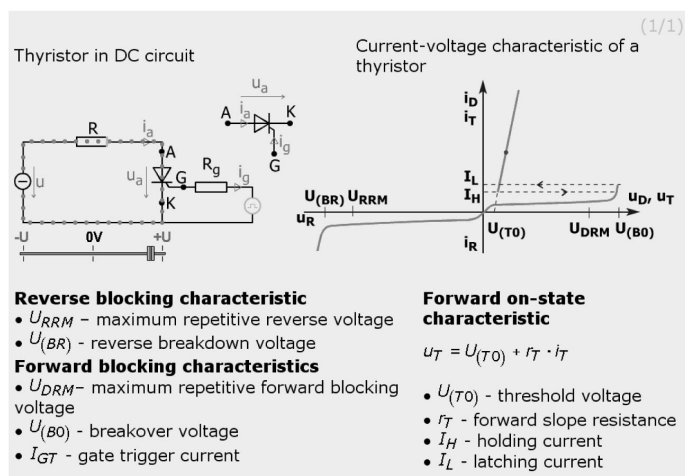
Fig. 4. Principal properties of thyristor—static main screen.

blocking state before it can begin to conduct, which can be achieved by applying the gate current (Fig. 6a). The magnitude and longitude of the gate signal, the value of the load resistor and load inductance (and thus load time) constant can be

changed, as is evident in Fig. 6c. The delay time t_{GD} is changed depending on the magnitude of the gate signal. Dragging of the temporal ledge by the mouse can find the instantaneous status of the turn-on process.



(a)



(b)

Figs. 5a and 5b. Static properties of thyristor—animation.

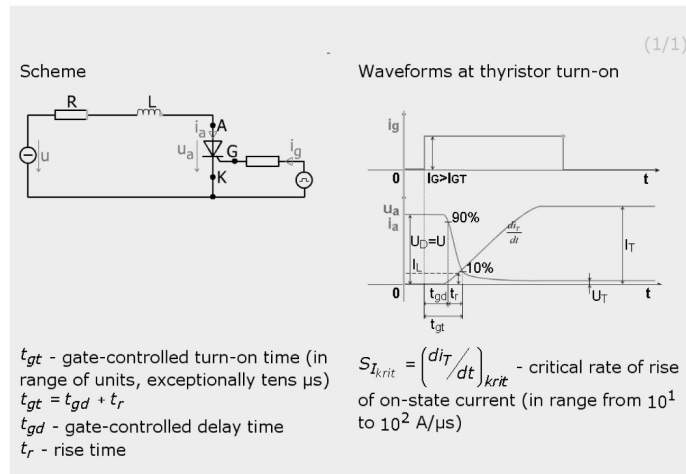


Fig. 6a. Dynamic properties at turn-on of thyristor—off-state.

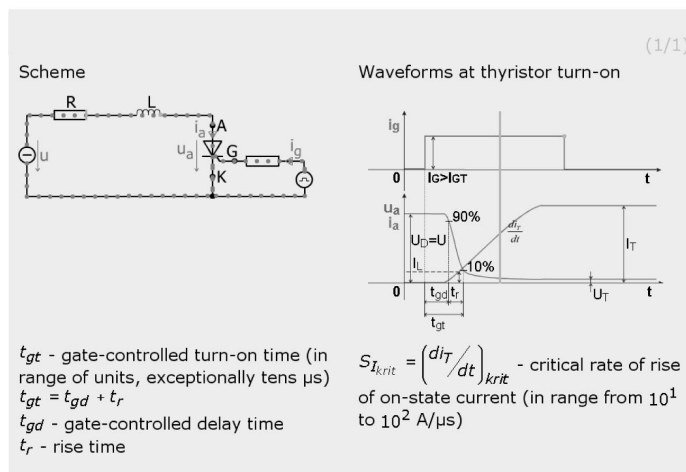


Fig. 6b. Dynamic properties at turn-on of thyristor—turn-on process.

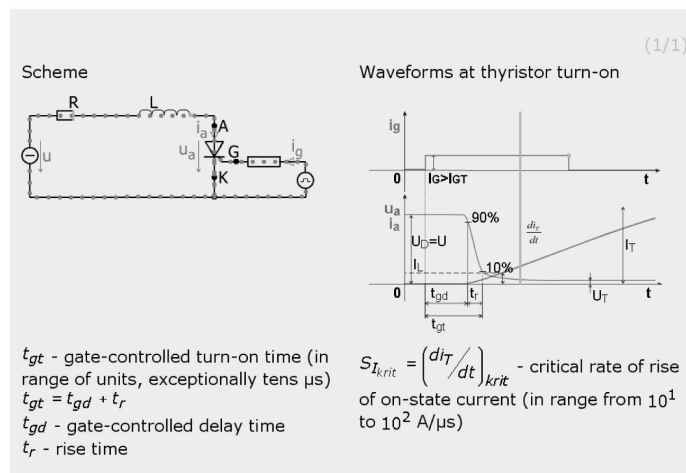


Fig. 6c. Dynamic properties at turn-on of thyristor—changed parameters R, L, I_G at turn-on process.

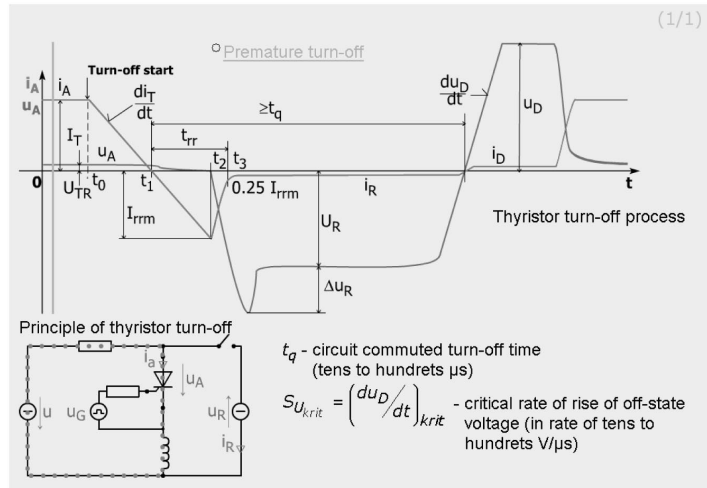


Fig. 7a. Dynamic properties at turn-off of thyristor—on-state.

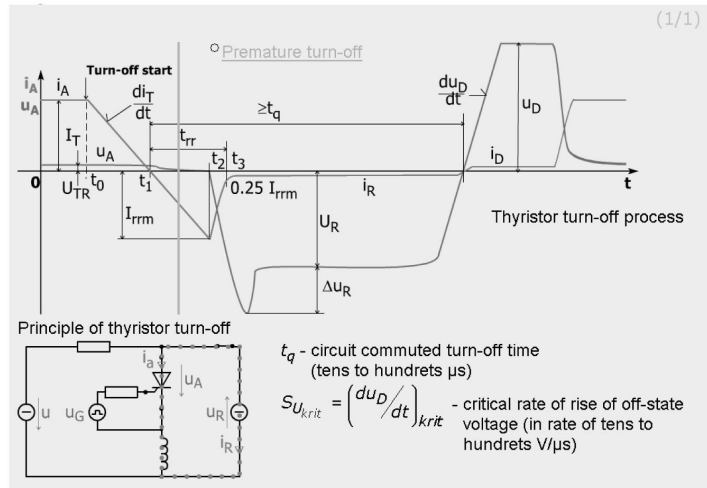


Fig. 7b. Dynamic properties at turn-off of thyristor—turn-off process.

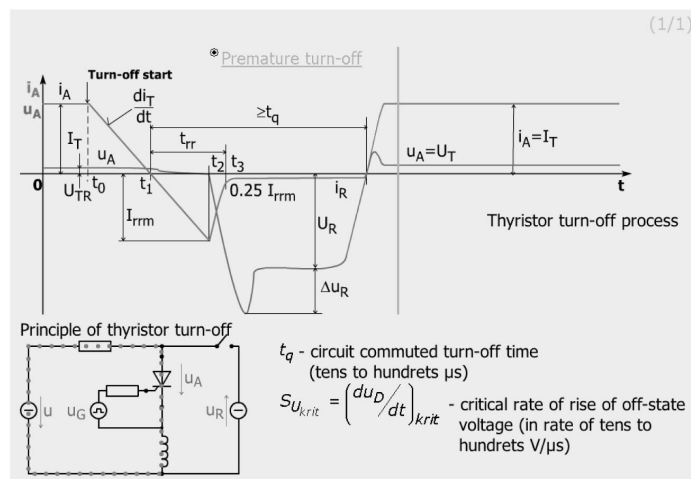


Fig. 7c. Dynamic properties at turn-off of thyristor—too short reverse bias time.

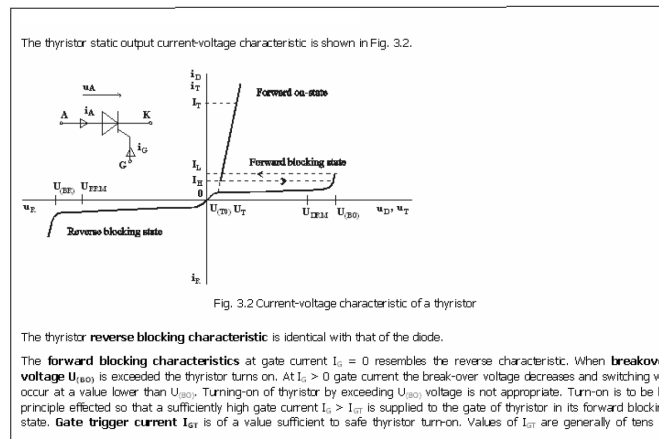


Fig. 8. Thyristor I-A characteristic—static sub-screen.

The dynamic properties at turn-off of the thyristor are explained in Figs. 7a, 7b and 7c. The thyristor status can be observed by moving the temporal ledge. Fig. 7c shows the situation when the length of the reverse voltage during the turn-off is not enough for recovery of the blocking capabilities of the thyristor.

Because the waveforms, illustrating the properties of power semiconductor devices, cannot, in most cases, be described by equations, changes in the waveforms can only be performed by alternation of magnitude and position of vector figures. As a result, more labour input was needed at their creation. The problem also lay in the fact that waveforms were drawn for real devices under real circumstances in circuit and thus the appropriate intervals of operation were not sharp-bounded. For all that (e.g. at movement of the temporal ledge in Figs. 6 or 7), some changes of status in the relevant scheme (especially the details) were not completely possible to designate. Besides this, some very small values were neglected, as, for instance, leakage currents at the off-state of the semiconductor devices. With figures it is possible to change the different parameters. For example, it is possible to change the value of the feeding voltage, resistance, inductance, etc., and consequently to follow the corresponding changes in time-dependent waveforms. It is possible to change the parameters of some of

the quantities (e.g. temperature, rate of rise, rate of fall, etc.) in animate time-dependent waveforms and consequently watch specific changes in other quantities.

CONCLUSION

E-learning methods utilizing animations and interactivity can markedly assist in faster absorption of knowledge and new information. This is a form of study that students are already prepared for and that is also able to enhance their interest in study areas that are considered difficult, demanding technical and logical thinking. Teaching by this method permits faster and superior understanding of a given problem, particularly in the teaching of power electronics and power semiconductor devices. This then provides a good basis for understanding the operation of converters and their correct design and dimensions.

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