

Characterization and Modeling of Power Electronics Device

M. N. Tandjaoui, C. Benachaiba, O. abdelkhalek, B. Denai, Y. Mouloudi

University of Bechar, Department of Technology, BP 417 Algeria

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ABSTRACT

During the three decades spent, the advances of high voltage/current semiconductor technology directly affect the power electronics converter technology and its progress. The developments of power semiconductors led successively to the appearance of the elements such as the Thyristors, and become commercially available. The various semiconductor devices can be classified into the way they can be controlled, uncontrolled category such as the Diode when it's on or off state is controlled by the power circuit, and second category is the fully controlled such as the Metal Oxide Semiconductor Field Effect Transistor (MOSFET), and this category can be included a new hybrid devices such as the Insulated Gate Bipolar Transistor (IGBT), and the Gate Turn-off Thyristor (GTO). This paper describes the characteristics and modeling of several types of power semiconductor devices such as MOSFET, IGBT and GTO.

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Corresponding Author:

Abdelkhalek Othmane,
Department of Technology,
University of Bechar,
Bechar University Center BP 417 Bechar 08000, Algeria.
Email: chellali@netscape.net

1. INTRODUCTION

Power electronics is the technology of converting electric power from one form to another using electronic power device. It also refers to a subject of research in electrical engineering which deals with design, control, computation and integration of nonlinear, time varying energy processing electronic systems with fast dynamics. With "classical" electronics, electrical currents and voltage are used to carry information, whereas with power electronics, they carry power. Thus, the main metric of power electronics becomes the efficiency. The capabilities and economy of power electronics system are determined by the active devices that are available. Their characteristics and limitations are a key element in the design of power electronics systems.

Several types of solid state power semiconductor devices have been developed to control of output parameters, such as voltage, current or frequency. In a state power converter, the power semiconductor devices function as switches, which operate statically, that is, without moving contact [1].

A semiconductor material is one whose electrical properties lie in between those of insulators and good conductors. Examples are: germanium and silicon. In terms of energy bands, semiconductors can be defined as those materials which have almost an empty conduction band and almost filled valence band with a very narrow energy gap (of the order of 1 eV) separating the two. Semiconductor may be classified as under:

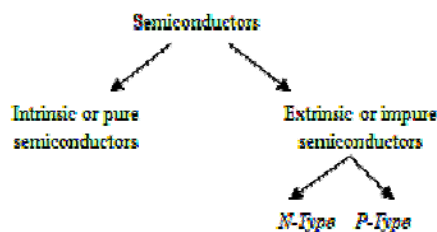


Figure 1. Type of Semiconductors

An intrinsic semiconductor is one which is made of the semiconductor material in its extremely pure form. Alternatively, an intrinsic semiconductor may be defined as one in which the number of conduction electrons is equal to the number of holes.

Those intrinsic semiconductors to which some suitable impurity or doping agent or doping has been added in extremely small amounts (about 1 part in 10⁸) are called extrinsic or impurity semiconductors [4], [5]. Depending on the type of doping material used, extrinsic semiconductors can be sub-divided into two classes, N-type semiconductors and P-type semiconductors.

The first power electronic device started in 1902 with the development of mercury arc rectifier using to convert alternating current (AC) into direct current (DC). In modern systems the conversion is performed with semiconductor switching devices such as diodes, thyristors and transistor, and others hybrid devices beginning in the 1950s such as SCR, MOSFET, GTO, IGBT... The development of power semiconductor devices has always been a driving force for power electronics systems. In the semiconductor industry, we all understand the importance of design, material selection, assembly manufacturing, reliability, and testing in minimizing power packaging failures [4], [2]. For a long time silicon-based power devices have dominated the power electronics and power system applications.

The semiconductor industry has made impressive progress, particularly in communications, health, automotive, computing, consumer, security, and industrial electronics.

Power handling and dissipation of devices is also a critical factor in design. The current rating of a semiconductor device is limited by the heat generated within the dies and the heat developed in the resistance of the interconnecting leads. Semiconductor devices must be designed so that current is evenly distributed within the device across its internal junctions, its forward voltage drop in the conducting state translates into heat that must be dissipated when they require specialized heat sinks or active cooling systems to keep their junction temperature from rising too high. Exotic semiconductors such as silicon carbide have an advantage over straight silicon in this respect, and germanium, once the main-stay of solid-state electronics is now little used due to its unfavorable properties at high temperature.

In the 1980s, the development of power semiconductor devices took an important turn when new process technology was developed that allowed integration of MOS and bipolar junction transistor (BJT) technologies on the same chip. Thus far, two devices using this new technology have been introduced: insulated bipolar transition (IGBT) and MOS controlled thyristor (MCT). Many integrated circuit (IC) processing methods as well as equipment have been adapted for the development of power devices. However, unlike microelectronic ICs, which process information, power device ICs process power and so their packaging and processing techniques are quite different [2], [5].

Several attributes dictate how devices are used. Devices such as diodes conduct when a forward voltage is applied and have no external control of the start of conduction. Power devices such as SCRs and thyristors allow control of the start of conduction, but rely on periodic reversal of current flow to turn them off. Devices such as GTO, IGBT, and MOSFET provide full switching control and can be turned on or off without regard to the current flow through them. The control input characteristics of a device also greatly affect design; sometimes the control input is at a very high voltage with respect to ground and must be driven by an isolated source. As efficiency is at a premium in a power electronic converter, the losses that a power electronic device generates should be as low as possible.

Even though the technologies with silicon (Si)-based power devices are mature, inherent material restrictions limit their performance in high voltage, high power, high switching frequency and high temperature applications. Bipolar power devices, such as insulated-gate bipolar transistors (IGBTs), can handle high power, but the switching speed is limited by the devices' structure. Unipolar power devices, like metal-oxide semiconductor field effect transistors (MOSFETs), can be switched at high frequency, but suffer from relatively high on-state resistance. Furthermore, Silicon power devices generally can only withstand

operational temperature of 150°C and can require a substantial cooling system [3].

A gate turn-off thyristor (known as a GTO) is a three-terminal power semiconductor device that belongs to a thyristor family with a four-layer structure. They also belong to a group of power semiconductor devices that have the ability to fully control on and off states via the control terminal (gate). The design, development, and operation of the GTO are easier to understand if we compare it to the conventional thyristor. Like a conventional thyristor, applying a positive gate signal to its gate terminal can turn on a GTO. Unlike a standard thyristor, a GTO is designed to turn off by applying a negative gate signal [2], [4], [7].

The aim of this paper is to present the principles underlying power conversion by the use of static switches and the techniques employed for controlling output parameters such as voltage, current, power, frequency and waveform. We shall present a characteristic and modeling of two types of power electronics devices such as IGBT and GTO and its results of simulation when we used the MATLAB/SIMULINK to simulate these devices. In a progressive sequence, we shall present all the important types of power converters that have proved useful in the application areas of electric power. We shall also present important application areas, and this will bring out how converter schemes and control strategies can be tailored to meet specific needs.

2. CHARACTERIZATION AND MODELING OF POWER ELECTRONICS DEVICES

The controlled valves, IGBT and GTO, take a significant place in converters of all kinds. As these new types of valves can as well cut conduction as to start it, the IGBT and the GTO gradually replace the thyristors in the applications where one was formerly to call upon forced commutation.

2.1. GTO Thyristor Characteristic

This semiconductor device, as the name implies, is a hybrid device that behaves like a thyristor. However, it has an added feature that the provide gate control allows the designer to turn the device on and off if and when desired [ebook_Power Electronic Control in Electrical Systems]. The symbol for a GTO and i-v characteristics are plotted in figure 1 (a) and (b) respectively.

A high degree of interdigitation is required in GTOs in order to achieve efficient turn-off. The most common design employs the cathode area separated into multiple segments (cathode fingers) and arranged in concentric rings around the device center [2].

Apart from their ability to interrupt the anode current by injecting a current in the gate, the GTO are very similar to thyristors. The conduction of GTO is initiated by injecting a positive current in the trigger. To maintain conduction in the GTO, the anode current must not fall below a threshold called holding current. The anode current is blocked by injecting a current in the trigger substantial negative for a few microseconds. In order to ensure the locking, the current injected into the trigger must be about one-third of the current flowing in the anode. The GTO switches are therefore of great power, which can control the currents of a few thousand amps at voltages up to 4000v [7].

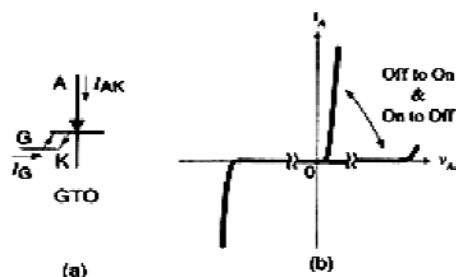


Figure 2. GTO; (a) circuit symbol; (b) i-v characteristics

It should be noted that although the GTO can be turned on like a thyristor, with a low positive gate current pulse, a large negative pulse is required to turn it off. These are relatively slow devices when compared with other fully controlled semiconductors.

The maximum switching frequency attainable is in the order of 1Khz. The voltage and current rating of the commercially available GTOs are compared to the thyristors approaching 6.5Kv, 4.5KA and are expected to increase to cover completely the area occupied by thyristor as [5].

A major variation on the thyristor is the GTO (Gate Turn-Off Thyristor). This is a thyristor where the structure has been tailored to give better speed by techniques such as accurate lifetime killing, fine finger or cell structures and "anode shorts" (short circuiting P+ and N- at the back in order to decrease the current gain of the PNP transistor). As a result, the product of the gain of both NPN and PNP is just sufficient to keep the GTO conductive. A negative gate current is enough to sink the whole current from the PNP and turn the device off.

A GTO shows much improved switching behavior but still has the tail as described above. Lower power applications, especially resonant systems, are particularly attractive for the GTO because the turn-off losses are virtually zero [6], [7].

2.2. IGBT Characteristic

The IGBT is a hybrid semiconductor device that literally combines of the MOSFET and BJT. The MOSFET is a transistor device capable of switching fast with low switching losses. It cannot handle high power and is mostly suited for low-power application. Thus, the BJT is so named because the conduction is due to the movement of electrons and holes within the transistor.

Specifically, it has the switching characteristics of the MOSFET with the power handling capabilities of the BJT. It is a voltage-controlled device like the MOSFET but has lower conduction losses. Furthermore, it is available with higher voltage and current ratings. There are a number of circuit symbols for the IGBT with the most popular and the typical i-v characteristics are plotted in Figure 4.

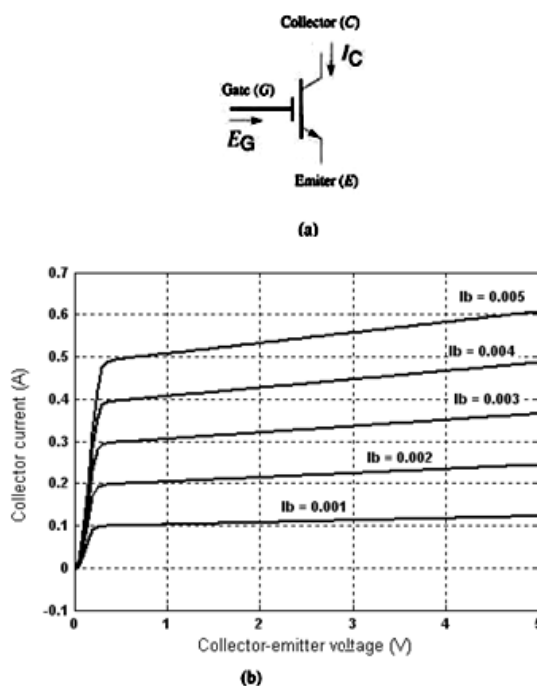


Figure 3. IGBT features; (a) circuit symbol; (b) i-v characteristics

The IGBTs are faster switching devices than the BJTs but not as fast as the MOSFETs. The IGBTs have lower on-state voltage drop even when the blocking voltage is high. The IGBT is the most popular device for AC and DC motor drives reaching power levels of a few hundred Kw. It has also started to make its way in the high voltage converter technology for power system application [5], [7].

The IGBT is a transistor whose conduction is primed and unprimed by applying an appropriate voltage on the trigger (the base). As in a conventional transistor, the three terminals are named C collector, emitter E and base B.

The IGBT can withstand much higher currents I_D of the MOSFET. Therefore, they can order higher powers. Compared with the GTO, the BJT, MOSFET and IGBT can initiate and interrupt the flow of anode current with greater speed. This allows these semiconductors to operate at much higher frequencies. This results in a reduction in the size, weight and cost of devices using these valves [7].

3. SEMICONDUCTOR SWITCHING-POWER PERFORMANCE

The power frequency ranges of the various semiconductors discussed in the previous sections are summarized in Figure 3. It is clear that the thyristor dominates the ultra-high power region for relatively low frequencies.

The GTO is the next device when it comes to power handling capabilities extending to frequencies of a few hundred Hz. The IGBT occupies the area of medium power with the ability to operate at relatively higher frequencies.

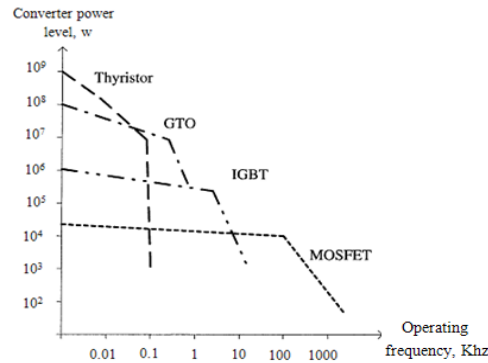


Figure 4. Power Converter Level and Frequency for Various Semiconductor Devices

The tendency over the next few years is to have the GTO extend its power area towards the thyristor level. At the same time, the IGBT will also extend its power ability towards the GTO with higher switching frequency [5].

4. MATLAB SIMULATIONS RESULTS

An analog simulation of power electronics devices such as MOSFET, IGBT and GTO is proposed in order to evaluate the behavior of this component in its electrical environment. In the first of this paper, the principal characteristics of GTO and IGBT are presented.

The Figure 5 showing the following out waveforms voltage's of supply, MOSFET, IGBT, and GTO. The setting with the state on is mainly subjected to the constraint of the blocking of the diode positioned. This is related to the reverse current of diode.

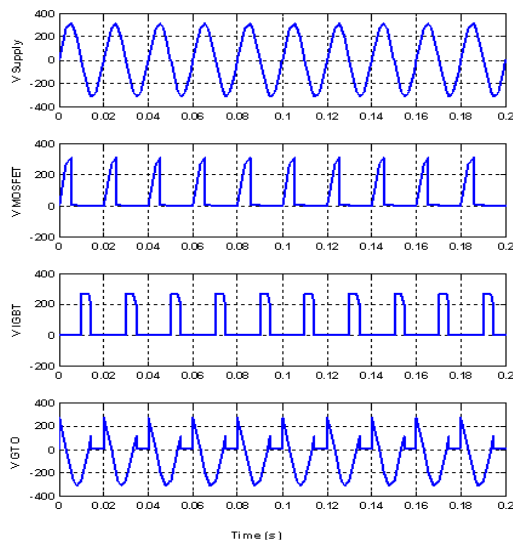


Figure 5. The Voltage Waveforms of Supply, MOSFET, IGBT and GTO

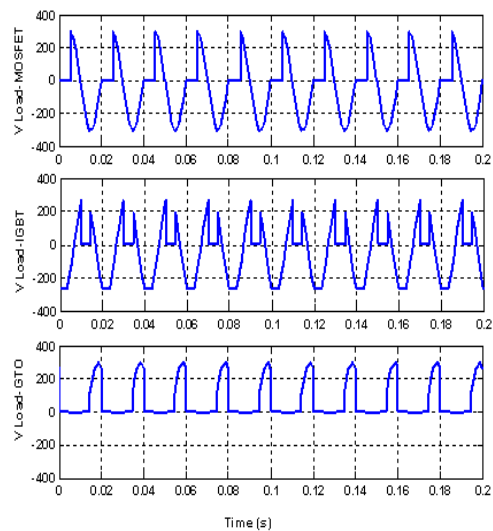


Figure 6. The Voltage Waveforms Loads with Devices MOSFET, IGBT and GTO

But the turn-on is also depend to the possible disturbances in the grid control, and just like for the phase of turn-off the behavior of the monolithic structures to closing is influenced by the impact of the circuit surrounding them.

In this all test of simulation for different components devices, the load is proposed as a resistance of 50Ω . In Figure 6, we can see the following forms of voltage of load when it is operated for these different electronics devices.

The waveforms of current in output of these devices can be observed in Figure 7 and show that the current fluctuation with the setting the state on component is quite present. However, the quantity of current is depended to the current of covering of the diode. The waveforms of load currents are presented in Figure 8 are similar as these presented in figure7 because, in this case of study, we used a purely resistive load.

Finally, let us conclude from it that these electronics devices are major pollutants in the power quality, that us obliges taken into account their use in order to preserve the good quality of the power supply.

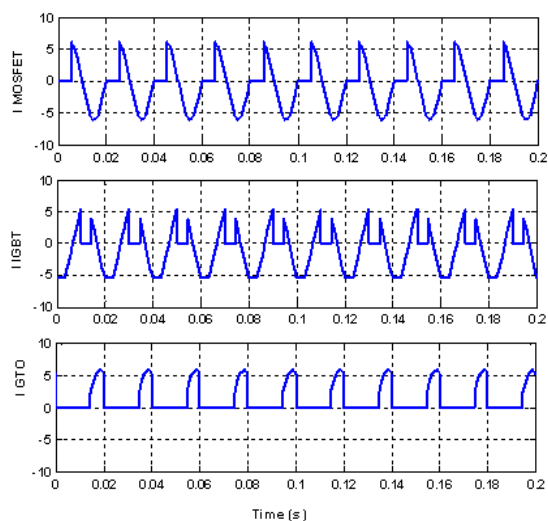


Figure7. The Current Waveforms Output of MOSFET, IGBT and GTO

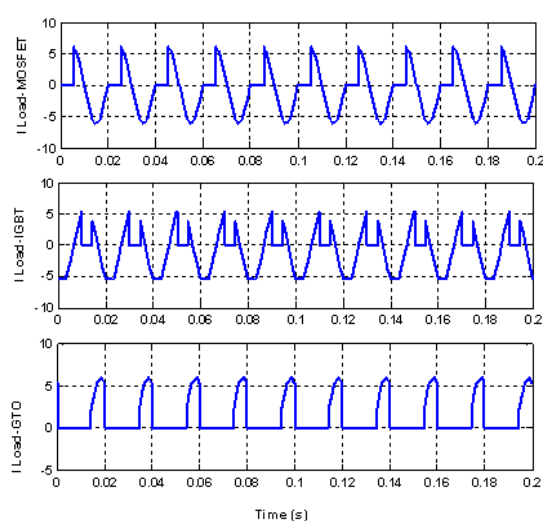


Figure 8. The Current Waveforms Loads Used MOSFET, IGBT and GTO

5. CONCLUSION

The electrical characterization of several active switches as MOSFET, IGBT and GTO was presented in this paper. The behavioral of these devices developed using MATLAB / SIMULINK when the power electronic circuits are simulated before they are produced to test how the circuits respond under certain conditions in electrical aims application.

The study theoretical approach of these electronic power component characteristics was presented. It is noteworthy that the behavior enables also to predict certain behaviors of this electronic power component in the electrical circuit.

Finally, the simulation of these electronics devices in real time permits to extract the state of the components is the application of electronics for the control and conversion of electric power. Applications of power electronics range in size from a switched mode power supply in an AC adapter, like FACTS (Flexible alternative current transmission systems) and DC motor drives used to operate pumps and to interconnect electrical grids with a novel technique of transmission based on power electronic like HVDC (high voltage direct current systems).

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BIOGRAPHIES OF AUTHORS



Mohammed Nasser Tandjaoui received the state engineer degree in Electrical Engineering in 2005 from the University of Sciences and Technology of Oran (USTO). He was born here Magister in electrical engineering in 2009 from university of Bechar, Algeria. He is teaching in university of bechar. He is preparing a Doctorat. His interests include power electronics, FACTS, HVDC, power quality issues, renewable energy and energy storage.



Benachaiba Chellali received the state engineer degree in Electrical Engineering in 1987 from the University of Boumerdes (INH) and the M.S. degree in 1996 from Bechar University Center, Algeria. In 2005 he received the doctorate degree from the University of Sciences and Technology of Oran (USTO), Algeria and currently holding the post of Assistant Professor. His current research and teaching interests are in the areas of power quality improvement, active power filters and renewable energy. Presently he is supervising five doctoral students working in the field of power quality and renewable energy.



Abdelkhalek Othmane was born in Taghit, Bechar (Algeria) in 1976. He received the Eng. degree from Bechar University Center in 2001, the Magister degree from Sidi-bel-Abbes University in 2004 and the doctorate from the University of Bechar in 2010. He is a member in the Laboratory of Physics and Semiconductor Devices. His research area interests are Power electronic, Power quality, Active filtering, DVR, UPQC, UPFC, Control, Digital control, Load flow Optimization.