MATHEMATICAL MODELING OF PROCESSES AND SYSTEMS

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INVERTER OF THE AUTOMATED SYSTEM FOR DETERMINING THE CHARACTERISTICS OF SEMICONDUCTOR DEVICES

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***Abstract*—*This article is devoted to the issues of building the inverter for automated determination system of semiconductor devices volt-ampere characteristics. In the article the structure of such a system is considered and it is proposed to use a half-bridge inverter with an inductive-capacitive filter to regulate the test voltage. In order to control the output current of such an inverter, it is proposed to use relay control, and control of the output voltage is proposed to be carried out indirectly through current regulation. The structure of the control device of such an inverter that implements the proposed approach to control is developed. Using the software environment MATLAB Simulink a virtual model of the inverter and its control device is built. The research of the developed system operation during the determining the volt-ampere characteristic of the semiconductor diode has been carried out. Obtained results confirmed the efficiency of the proposed approach.*

Index Terms—Determination of volt-ampere characteristics; half-bridge inverter; computer simulation.

I. INTRODUCTION

Semiconductor devices [1], [2] are electronic components made of semiconductor materials and the principle of which is based on the use of electron-hole junctions properties. Despite the development of technologies for the production of semiconductor devices, there are difficulties in accurately controlling the geometrical dimensions of active structures that form the p-n junction, the impurity concentration in different parts of the structure, quality, surface treatment and other parameters. This leads to the fact that the characteristics of the devices of the same type may differ from each other [3]. In addition, these characteristics are significantly dependent on external factors such as temperature.

The main static characteristics that represent the basic parameters of semiconductor devices are volt-ampere characteristics (VAC) [4]. Measurement and control of the characteristics of semiconductor devices is extremely important during the construction of complex electronic systems, since the accuracy of the characteristics of such devices has an absolute impact on the ability of the system to operate under given conditions.

During the production there is an output quality control of the finished product, but a certain percentage of the reject still remains. Therefore, when developing electronic devices and systems, input control of the characteristics of semiconductor devices is carried out.

The main means for measuring the VAC and parameters of semiconductor devices are:

– a set of standard measuring devices for manual measurement of VAC and parameters of semiconductor devices;

– specialized measuring devices for measuring parameters of semiconductor devices and integrated circuits;

– specialized devices – curve tracers for automatic measurement of VAC;

– automatic meters of VAC and semiconductor devices parameters based on personal computers.

The simplest method for finding VAC is the basic method of voltmeter-ammeter. In accordance with this method, the electrodes of the semiconductor device are connected to the controlled sources of the EMF, or current, and with the help of measuring devices – voltmeters and ammeters, the voltages and currents in the semiconductor devices circuits at different values of the EMF or the current of the sources are measured. The use of such approaches to the measurement of characteristics requires the involvement of experts with experience in the field of measurement, as well as the availability of specialized measuring equipment. In addition, the time spent to study semiconductor elements is significant, and therefore the use of such a method is not appropriate.

Another approach to determining the characteristics of semiconductor elements is the use of specialized devices called the curve tracers. Such devices usually include a complete set of electronic measuring devices that have a complex structure and are intended for laboratory measurements. Curve tracers are usually the most automated devices. In general, these devices have high accuracy of measurements, user-friendly research scheme, and do not require additional equipment.

The modern means of automated measurement of VAC and parameters of semiconductor devices are VAC meters, implemented on the basis of computer measurement technology. The hardware of such meters includes a PC and a data acquisition device that corresponds to the general structure of computer measurement systems with a semiconductor device as an object under study. The data acquisition device contains analogue and digital I/O channels, through which the interaction of a PC with a semiconductor device is carried out. Through the analog output channels the necessary test effects, which are formed by the generators of the sweep and step function, are transmitted to the semiconductor device. Through analogue input channels, the values of the voltages and currents of the analyzed semiconductor device converted into digital codes are transmitted to the PC. Digital I/O channels are used to control the measuring complex.

Using such systems allows measuring of the semiconductor devices characteristics with high accuracy, but their cost is extremely high. Therefore, the tasks of developing automated systems for determining the characteristics of semiconductor devices or their components are relevant.

II. MAIN MATERIAL

To develop the structure of the system, it is necessary to define its basic functional capabilities. First of all, the system should create conditions for measuring the volt-ampere characteristics of devices, so it should act like an adjustable current or voltage source. Secondly, the system should measure these values with a given accuracy in a given range of values and properly process them. Thirdly, the system must be integrated with a personal computer, with which the user can set the modes of operation and get the results of measurements.

Based on these capabilities, the structure of the system will look as shown in Fig. 1.

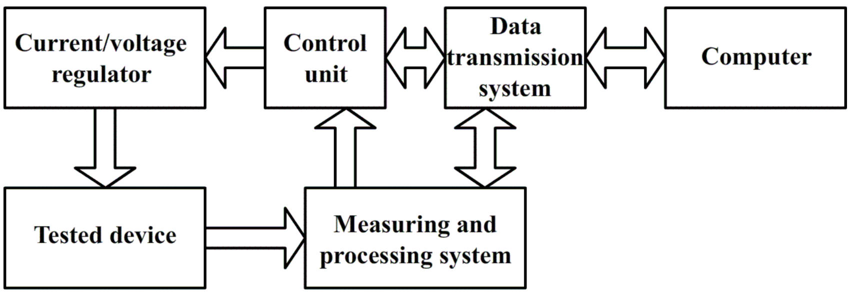

Fig. 1. The structure of the automated system for determining semiconductor devices characteristics

The proposed system includes current or voltage regulator, device for controlling it, system for measuring and processing data, and system for data transmission to personal computer. Using the software installed on the PC, the operator sets the type of semiconductor device and mode of research. This data is transmitted to the control unit and measuring system. After this, the measurement procedure begins, during which the regulator generates the test signals required for the research, and the measurement system records the values of the studied parameters. In parallel with this measured data are processed and transmitted through the data transmission system to a personal computer. After the completion of the entire procedure, the measured data is available to the operator for further use.

The key issue in the construction of this system is the development of an electric energy converter, which would perform a voltage or current control function depending on the task. This is due to the fact that semiconductor devices are characterized by significant nonlinearity of VAC. For example, in the study of a semiconductor stabilizer on the VAC section before electrical breakdown, an electrical voltage should be regulated, and after – the current. In addition, depending on the type of device being studied, it is necessary to change the voltage or current polarity.

So, the purpose of these studies is to develop a converter of electrical energy with the properties of an adjustable source of current and voltage.

One possible solution may be a half-bridge inverter with an inductive-capacitive filter [6] powered by two independent DC sources. The scheme of such an inverter is shown in Fig. 2.

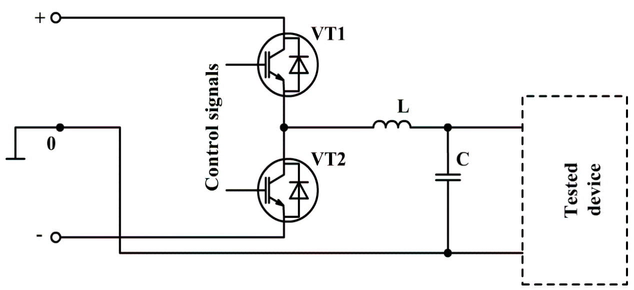

Fig. 2. Half-bridge inverter with inductive-capacitive filter

At the output of such an inverter, a rectangular voltage is formed which is fed to an LC filter. The low-frequency voltage components by this filter are skipped, and the high-frequency components are suppressed. Thus, by providing the corresponding control signals, it is possible to form the voltage of the desired pattern at the output of the filter.

The transfer characteristic of such a filter is determined according to the expression:

$$K(\omega) = \frac{R}{R + j\omega L - \omega^2 LCR},$$

where ω is the angular frequency; R is the load resistance.

The resonant frequency of such a filter is determined by the expression:

$$\omega_{\text{res}} = \frac{1}{\sqrt{LC}}.$$

Taking into account that the differential resistance of semiconductor devices can vary widely, in series with the tested device it is necessary to connect active resistance. The amplitude-frequency characteristics of this filter at values L = 30 mH, C = 100 uF and two values of load resistance: the infinite value and the value of 10 ohms are shown in Fig. 3.

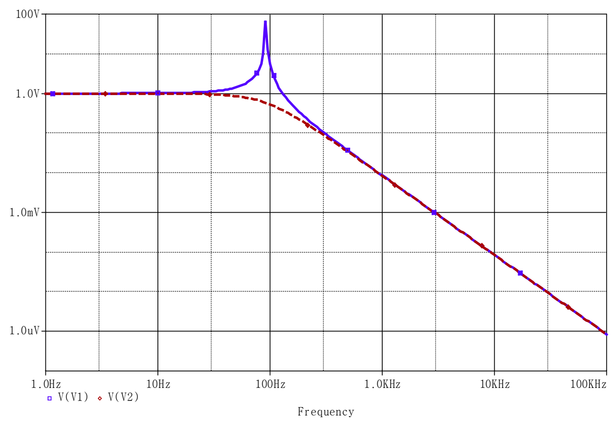

Fig. 3. Transmission characteristics of the inductive-capacitive filter at different loads

To determine the volt-ampere characteristic, it is necessary to measure the constant component of the current, and the use of such a filter makes it possible to significantly reduce the high-frequency component of the voltage applied to the tested device.

The formation of a inverter voltage or current of a given pattern is achieved by supplying control signals. Usually, high-frequency pulse-width modulation is used for this. To ensure the implementation of both current and voltage control two-circuit regulation should be implemented: the inner circuit will provide current control, and external – voltage.

The functional structure of the control device that implements this approach is shown in Fig. 4.

The principle of such a system is as follows:

– The internal circuit implements the relay control of the inverter current. The inverter current setting signal U_I^* is either supplied from the external control loop or from an independent input device and is limited to the maximum level. The choice of this signal source is carried out depending on its value – in the case when the signal from the control circuit exceeds a certain value, switching to an external source is carried out. The setting signal and the feedback signal U_I are fed to the inputs of the subtraction device, the output of which generates an error of current regulation ΔU_I. This error signal is applied to the input of the relay element (RE). When the error reaches the limit value set by the width of the relay element hysteresis loop, the signal at its output changes to the opposite. The high and low output level of the relay element is the control signals for the transistors of the inverter. An Inverting circuit is used to receive the second control signal. Such control provides value of the inverter current in the given current "corridor".

– The external circuit is used to regulate the voltage. The voltage setting signal U_U* is formed depending on the task received from the operator for the research of the semiconductor device. Next, this signal, together with the voltage feedback signal U_U, is fed to the input of the subtractor, the output of which generates an error voltage control signal ΔU_U. The received signal is fed to the input of the controller unit, which can be realized by various standard regulators. At the output of this block, the current setting signal is generated.

Thus, the proposed system implements subordinate regulation, and voltage regulation is carried out through regulation of current.

The analysis of the efficiency of such a system will be carried out through simulation. To do this, in the MATLAB Simulink software environment [7], a virtual model of the proposed system should be constructed. For simulation, elements from the Simscape section libraries would be used. These libraries include a variety of electrical elements, power supplies, semiconductor devices, measuring elements, and more.

The structure of the constructed model is shown in Fig. 5.

To analyze the system's performance, the process of forming a linearly varying voltage would be considered. In this case, the current setting signal is limited to a value equal to 1 A. As a researched semiconductor device, we will take a diode which model is represented as a nonlinear VAC. The voltage setting signal is equal to zero before the time of 0.1 s. After that, it starts to rise linearly to a value of 10 V at a time of 0.2 s. Then it linearly decreases to zero at a time of 0.3 s, and then remains unchanged. At a time of 0.4 seconds, it begins to decrease linearly and reaches a value of -100 V at a time of 0.5 s. These values of voltages are reduced to the voltages in the circuit, that is, the transmission coefficients of the sensors are not taken into account. The value of the inverter power supply voltage is equal to 150 V. As a regulator, a proportional controller, with a unit transmittance, is used. The width of the relay element hysteresis loop is ± 0.03 A.

The simulation results are shown in Fig. 6.

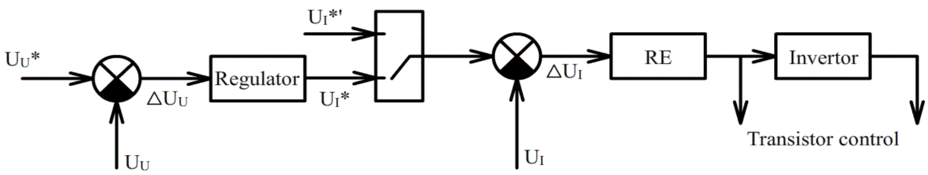

Fig. 4. The structure of the inverter control unit

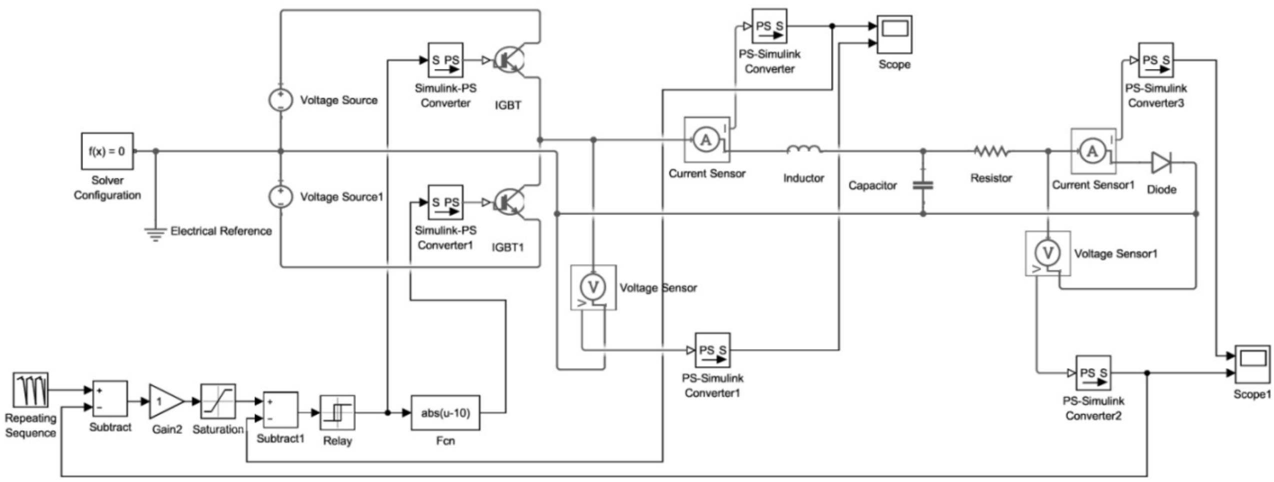

Fig. 5. Structure of a regulated inverter model

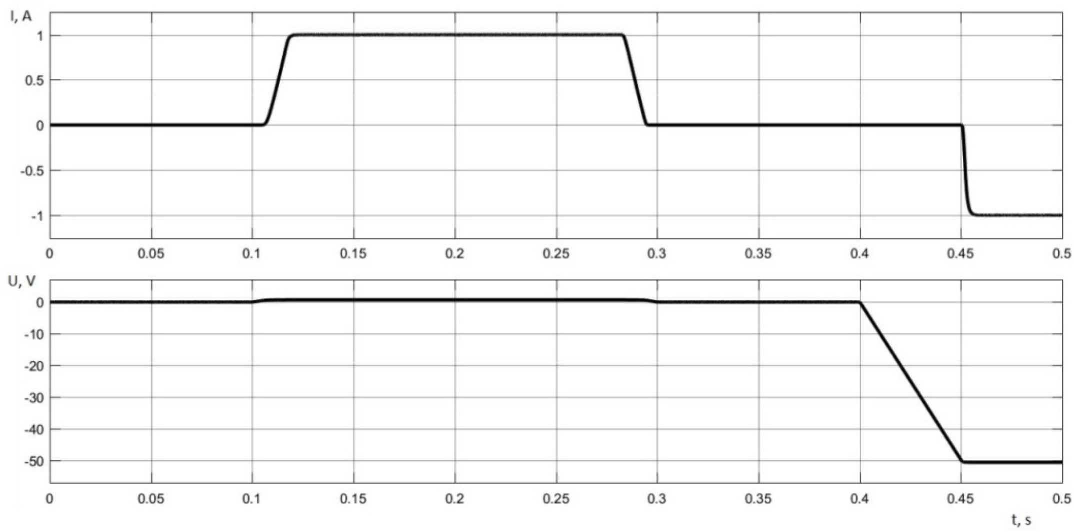

Fig. 6. Inverter output current and voltage graphs

In these graphs time dependences of current through the diode and the voltage on it are shown. The obtained results on an enlarged scale are shown in Fig. 7.

As can be seen from the graphs shown, as the setting signal grows, the voltage on the diode is also increased. The current is also increased, but the nonlinearity between these two dependencies is noticeable. The combination of current and voltage values at the same time points forms the semiconductor device VAC. After current reaching the value of 1 A, it ceases to increase, which is due to the used control approach. This corresponds to the boundary point of the investigated VAC.

When connecting the negative voltage (see Fig. 6), the voltage begins to decrease linearly to the value of -50 V, and the current value is almost unchanged and equal to the reciprocating current of the diode. At an voltage of -50 B there is an electrical breakdown, and the current begins to grow rapidly. This process continues until the current reaches a value of -1 A, after which it is limited and remains unchanged. Similarly to the straight branch of the VAC, a set of current and voltage values at the same time points determine the reverse branch of the VAC.

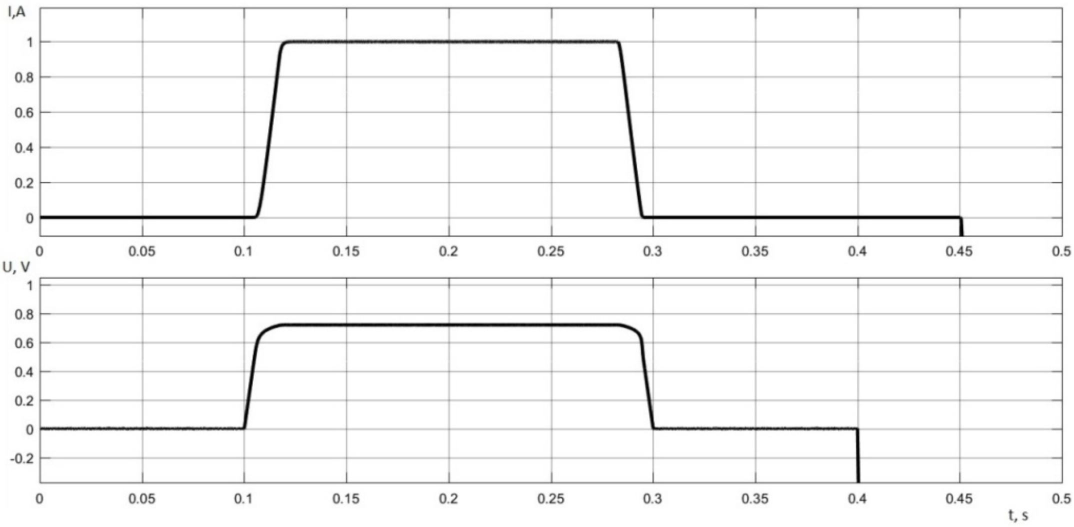

Fig. 7. Inverter output current and voltage graphs (enlarged scale)

For determining the volt-ampere characteristics of semiconductor devices with the number of outputs greater than two, a similar approach can be used to construct additional current or voltage regulators.

A characteristic feature of the implemented in this system approach is that there is no need for the exact formation of the voltage applied to the tested device. It is only necessary to ensure its smooth change in the considered range. The definition of VAC is carried out by fixing an array of measured values of current and voltage at the same time points. To improve accuracy, this procedure can be repeated several times with subsequent statistical processing of the results.

III. CONCLUSIONS

The structure of the automated system for determining the volt-ampere characteristics of semiconductor devices is described in the article. For the implementation of an adjustable voltage or current source, it is suggested to use a half-bridge inverter with inductive-capacitive filter. The control system of such an inverter, which implements subordinate voltage regulation through current regulation, is developed. The virtual model of the inverter is developed and researches of its operation are carried out. The obtained results confirmed the correctness of the proposed approach to current and voltage regulation

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О. В. Стаценко, Є. Л. Шилін. Інвертор автоматизованої системи визначення характеристик напівпровідникових приладів

Дана стаття присвячена вирішенню питань побудови інвертора для автоматизованої системи визначення вольт-амперних характеристик напівпровідникових приладів. В статті розглянута структура такої системи та запропоновано для регулювання тестової напруги використовувати напівмостовий інвертор з індуктивно-ємнісним фільтром. Для керування вихідним струмом такого інвертору запропоновано використати релейне регулювання, а керування вихідною напругою запропоновано здійснювати опосередковано через регулювання струму. Розроблено структуру пристрою керування таким інвертором, що реалізує запропонований підхід до керування. З використанням програмного середовища MATLAB Simulink побудована віртуальна модель інвертору та пристрою керування ним. Проведені дослідження роботи розробленої системи при визначені вольт-амперної характеристики напівпровідникового діоду. Отримані результати підтвердили працездатність запропонованого підходу.

Ключові слова: визначення вольт-амперних характеристик; напівмостовий інвертор; комп'ютерне моделювання.

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А. В. Стаценко, Е. Л. Шилин. Инвертор автоматизированной системы определения характеристик полупроводниковых приборов
Данная статья посвящена решению вопросов построения инвертора для автоматизированной системы определения вольт-амперных характеристик полупроводниковых приборов. В статье рассмотрена структура такой системы и предложено для регулирования тестового напряжения использовать полумостовий инвертор с индуктивно-емкостным фильтром. Для управления выходным током такого инвертора предложено использовать релейное регулирование, а управление выходным напряжением предложено осуществлять опосредованно через регулирование тока. Разработана структура устройства управления таким инвертором, реализующего предложенный подход к управлению. С использованием программной среды MATLAB Simulink построена виртуальная модель инвертора и устройства управления ним. Проведенные исследования работы разработанной системы при определении вольт-амперной характеристики полупроводникового диода. Полученные результаты подтвердили работоспособность предложенного подхода.
Ключевые слова: определение вольт-амперных характеристик; полумостовой инвертор; компьютерное моделирование.

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