Chapter 7

Software for Simulation of Static Switch Controllers

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Additional information is available at the end of the chapter

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Abstract

In the power supply systems, static converters are increasingly used to feed every kind of consumers. Static converters are used widely in electric drive systems for the change in voltage and/or frequency power of electric machines. The authors realized a Windows software application to simulate the static converter function which is used for better understanding of the students. This software is realized like an independent application helping with Visual Basic software package.

Keywords: static switch converters, software development, Visual Basic, operating regime simulation

1. Introduction

The development of industrial automation leads by default also to the improvement of electrical drive systems as more than these systems represent the most spread conversion type of the electrical energy in the mechanical energy.

Hereby, by an adequate command given by a controller into a close circuit, the static converters adjust the output electrical energy parameters, to the necessity demand by an electrical motor.

The static switch controllers are converters where the exit size has the same form with the entry size. By changing the control angle of the converter thyristor is obtained a variation of the effective/average value of the output voltage [2, 3].

2. AC switch controllers

2.1. Single-phase AC switch controllers

In the case of these static converters, the control angle α of the thyristor is defined as the angle determined from the time of zero crossing of the voltage up to input in conduction of the thyristor [2, 5].

The AC switch controllers are AC to AC static converters. The converter output voltage is chopped so that the RMS value of AC output voltage is modified with change of the switching period of the power semiconductors.

Figure 1 shows a single-phase AC switch controller scheme and the voltage waveforms. The switching angle α can be modified between 0 and π. If the switching angle is $\alpha = 0$, the output voltage is $u_s = u_{smax}$ [3].

The instantaneous value of output current is given by Eqs. (1–3) [2, 5]:

- For resistive load:

$$i = \begin{cases} \frac{U_m}{R} \sin \omega \cdot t & \text{for} \quad \omega \cdot t \in [\alpha, \pi] \cup [\pi + \alpha, 2\pi] \\ 0 & \text{for} \quad \omega \cdot t \in [0, \alpha] \cup [\pi, \pi + \alpha] \end{cases} \tag{1}$$

- For inductive load:

$$i = \begin{cases} U_m \left[\sin \left(\omega \cdot t - \frac{\pi}{2} \right) - \sin \left(\alpha - \frac{\pi}{2} \right) \right] \\ \quad for \quad \omega \cdot t \in [\alpha, 2\pi - \alpha] \cup [\pi + \alpha, 3\pi - \alpha] \\ \quad 0 \quad for \quad \omega \cdot t \in [0, \alpha] \cup [2\pi - \alpha, 2\pi] \end{cases} \tag{2}$$

- For resistive-inductive load:

$$i = \frac{U_m}{\sqrt{R^2 - (\omega \cdot L)^2}} \left[\sin (\omega \cdot t - \varphi) - e^{-\frac{R}{\omega \cdot L}(\omega \cdot t - \alpha)} \sin (\alpha - \varphi) \right] \tag{3}$$

The output current average value can be determined with Eqs. (4) and (5):

- For resistive load:

$$I_{med} = \frac{I_m}{2\pi} (1 + \cos \alpha) \quad \alpha \in [0, \pi] \tag{4}$$

- For inductive load:

$$I_{med} = \frac{2I_m}{2\pi} [\sin \alpha + (\pi - \alpha) \cos \alpha] \quad \alpha \in \left[\frac{\pi}{2}, \pi \right] \tag{5}$$

These values are useful for dimensioning of power semiconductor devices of the switch controllers.

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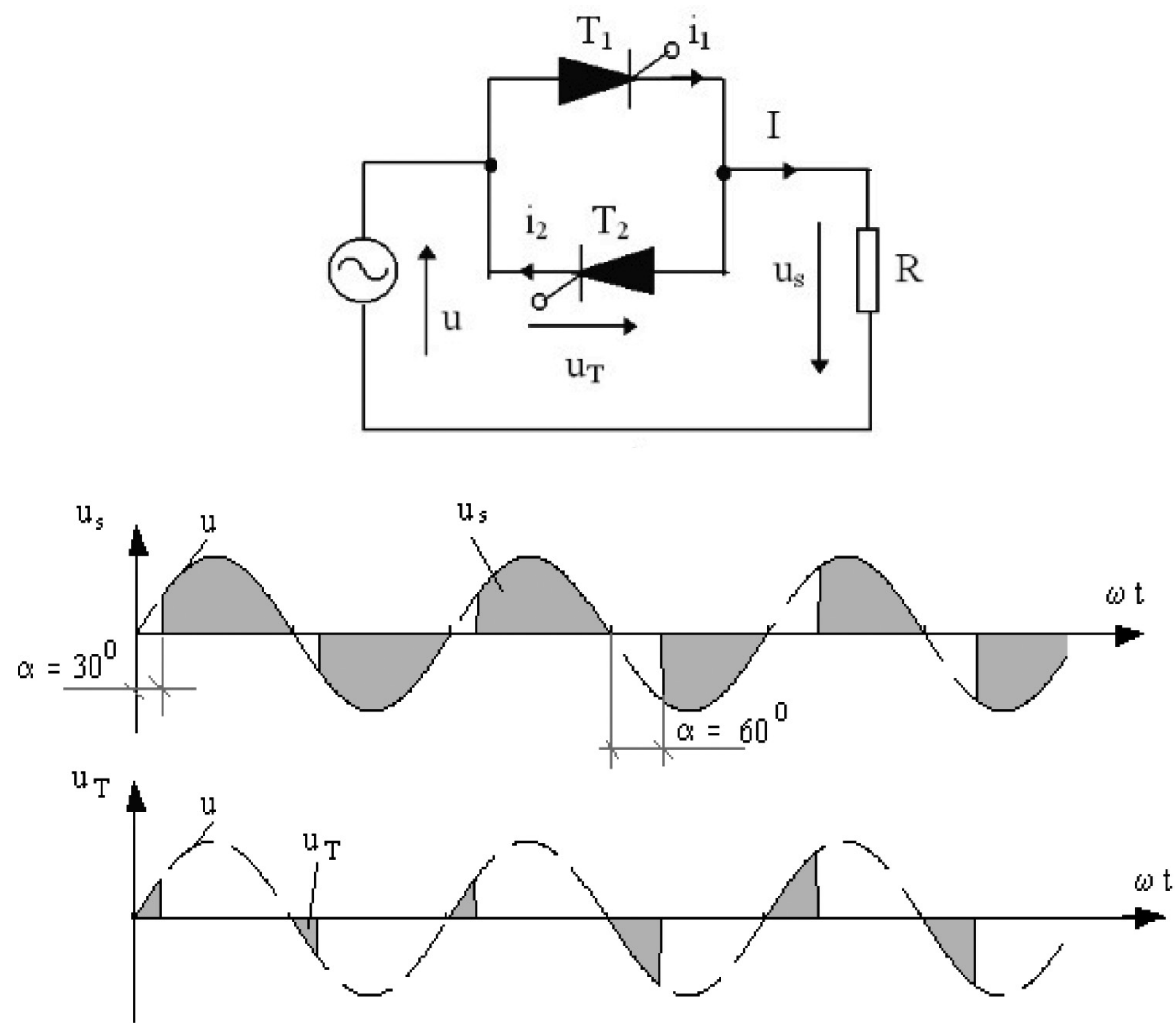

Figure 1. Single-phase AC switch controller electric scheme and the voltage waveforms.

The RMS output current is given by Eqs. (6) and (7) [2]:

- For resistive load:

$$I_{ef} = I_m \sqrt{\frac{1}{\pi}\left[\frac{1}{2}(\pi - \alpha) + \frac{1}{4}\sin 2\alpha\right]} \tag{6}$$

- For inductive load:

$$I_{ef} = I_m \sqrt{\frac{8}{\pi}\left[(\pi - \alpha)\left(\cos^2\alpha + \frac{1}{2}\right) + \frac{3}{4}\sin^2\alpha\right]} \tag{7}$$

Figure 2 presents the output current waveforms of the AC switch controller in the case of using different kinds of loads, and for different values of the switching angle α [5, 8].

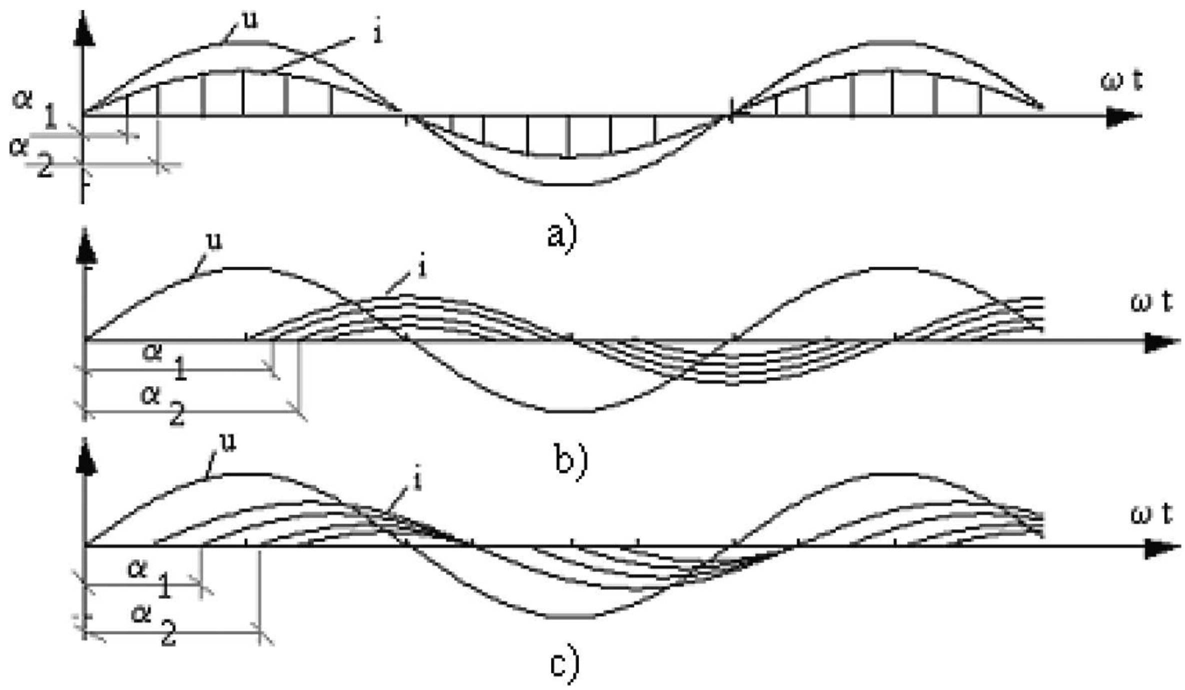

Figure 2. Current waveforms for a resistive load (a), inductive load (b), and a resistive-inductive one (c).

The AC switch controllers can be designed using only one thyristor. **Figure 3** presents the basic schemes and the output waveforms of these AC switch controller types.

2.2. Three-phase AC switch controllers

The three-phase AC switch controllers are designed using three single-phase AC switch controllers (k_R, k_S, k_T), one for each phase (**Figure 4**). The switching angle for each of the single-phase AC switch controllers is the same, but they must be phase angle with $2\pi/3$ [3].

By changing the control angle, α, of the thyristors from each phase, changes the power absorbed by load between the maximum value and zero. Order the thyristors is performed using of the control device grid (DC), which must ensure a phase shift of the control pulses of $2\pi/3$ between the phases [2, 5].

Variation the ignition angle of the voltages and of the currents depends on the load nature.

The voltage waveforms are determined from the vector diagram shown in **Figure 5**.

So, the voltage U_{KR} on a single-phase of R phase is zero on the period while one of two thyristors leads. The length of time while the thyristors are blocked, the load neutral point moves from 0 to 0′ and the voltage thyristor will be 3/2 U_R corresponding phasor $U_{0'\mathbf{R}}$. The voltage values are as follows:

- single-phase AC switch controller voltage is given by Eq. (8):

$$u_{kR} = \begin{cases} \frac{3}{2} u_R & \text{if} \quad k_R - \text{switch} - \text{off} \\ 0 & \text{if} \quad k_R - \text{switch} - \text{on} \end{cases} \tag{8}$$

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output line-to-line voltage is fit Eq. (9):

$$u'_{RS} = \begin{cases} u_{RS} & \text{if} \quad k_R, k_S - \text{switch} - \text{on} \\ -\dfrac{1}{2}u_{ST} & \text{if} \quad k_R - \text{switch} - \text{off} \\ -\dfrac{1}{2}u_{TR} & \text{if} \quad k_S - \text{switch} - \text{off} \end{cases} \tag{9}$$

output phase voltage (depending of the single phase switch converters which are in conduction) is given by Eq. (10):

$$u'_{R} = \begin{cases} 0 & \text{if} \quad k_R - \text{switch} - \text{off} \\ u_R & \text{if} \quad k_R, k_S, k_T - \text{switch} - on \\ \dfrac{1}{2}u_{RS} & \text{if} \quad k_T - \text{switch} - \text{off} \\ -\dfrac{1}{2}u_{TR} & \text{if} \quad k_S - \text{switch} - \text{off} \end{cases} \tag{10}$$

Figure 6 presents the voltage waveforms for a resistive load of an AC switch controller.

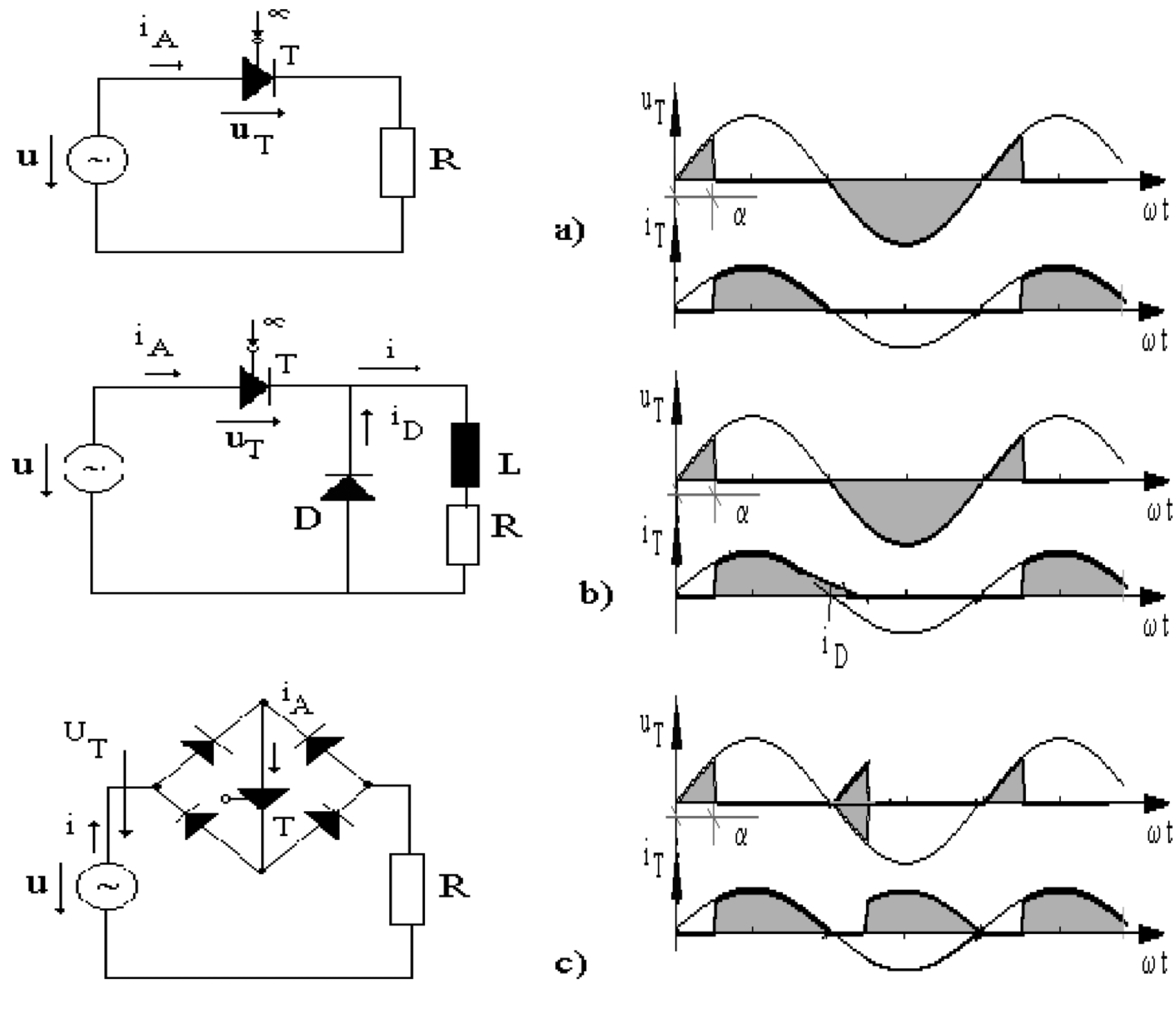

Figure 3. Basic schemes and output waveforms of different AC switch controllers: a) with one thyristor, b) with one thyristor and a diode, c) with one thyristor in a diode bridge.

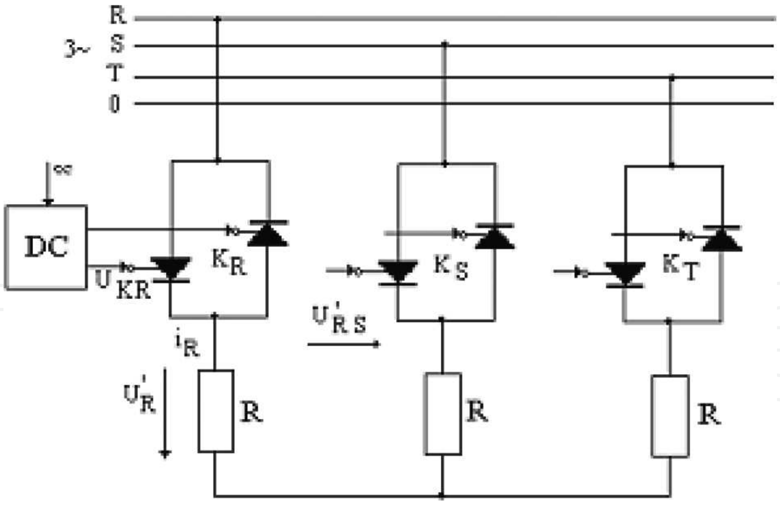

Figure 4. Three-phase AC switch controllers electric scheme.

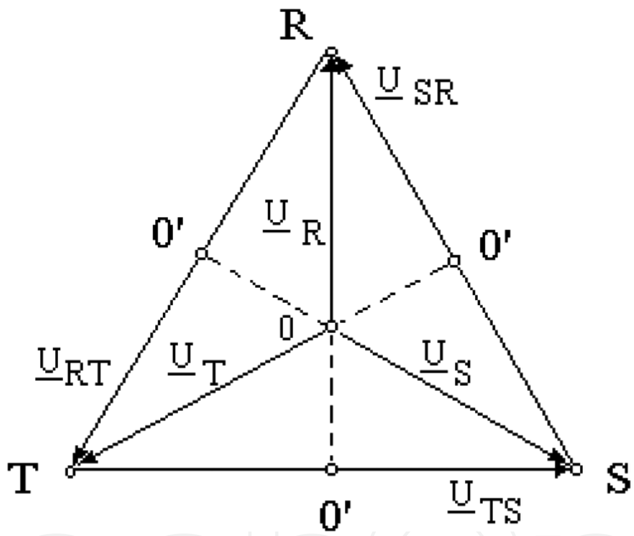

Figure 5. Vector diagram.

Because the load is resistive, the current waveform through the load is the same as the voltage phase raised on another scale.

In the case of an inductive load, the voltage waveforms are obtained similarly like in case of resistive load, but the thyristor ignition angle (α) is between ϕ and π, where φ is the delay angle between voltage and current due to the load. The current and voltage waveforms for an inductive are present in **Figure 7** [2, 3, 5].

If the three-phase AC switch controller supplies AC motors, the supply system must have the possibility to change the phase sequence to obtain a reversible drive system.

Figure 8 presents two schemes of AC switch controllers for reversible AC drive systems.

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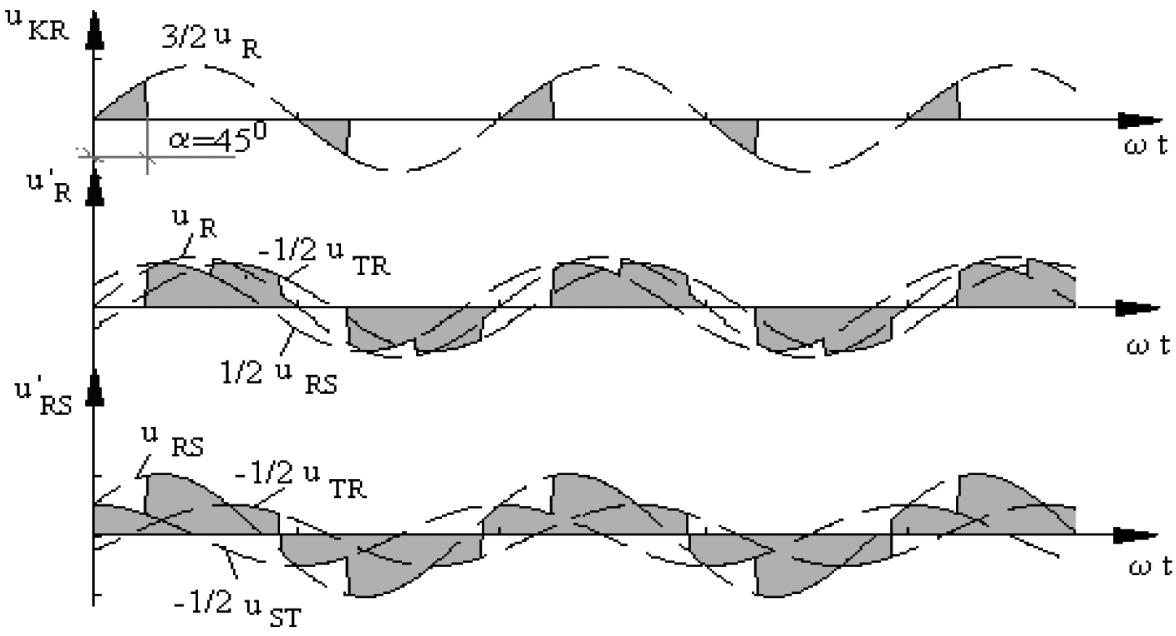

Figure 6. Voltage waveforms for a resistive load.

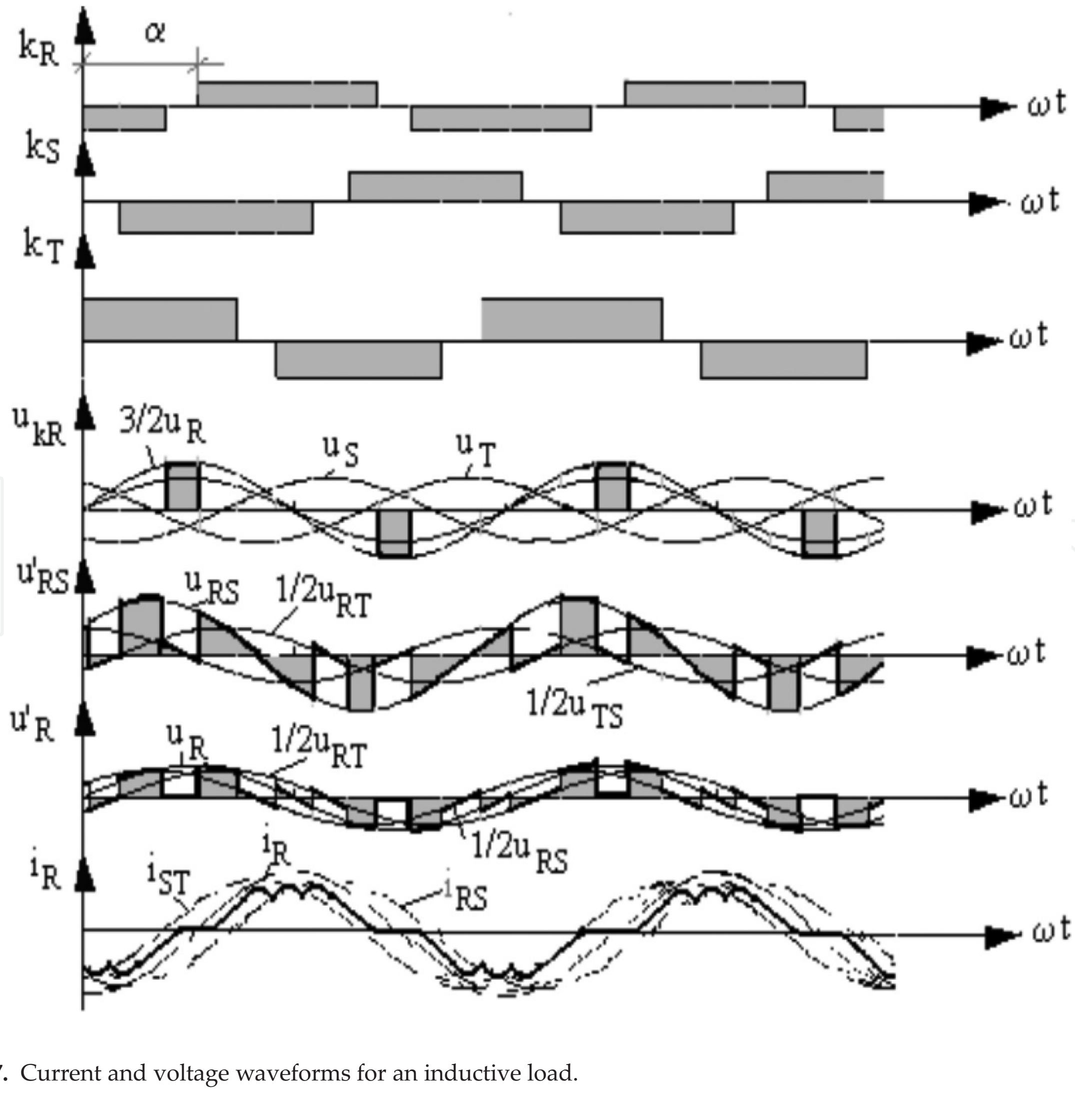

Figure 7. Current and voltage waveforms for an inductive load.

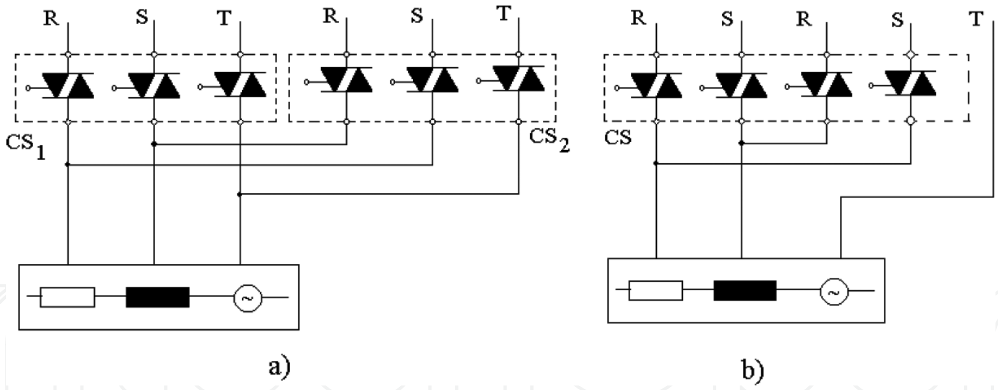

Figure 8. Reversible AC switch controllers: a) Symmetrical scheme, b) Non-symmetrical scheme.

3. Simulation of AC static switch controllers

The simulation of static switch function is realized like a Windows independent application helping with Visual Basic's software package [1, 4, 5]:

- It launches the simulation software.
- It opens the main simulation window of the switch controllers.
- In the main window, the user can choose the simulation type to be run with some radio buttons. The window also contains two buttons, one to continue the simulation (Continua) and the other to exit the application (Iesire) (**Figure 9**).
- It can choose the single-phase AC switch controller simulation, three-phase AC, or the chopper simulation using radio buttons.

Press the button for the continuation of simulation (Continua).

It opens the simulation window of the single-phase AC switch controller (**Figure 10**).

The simulation window containing three main parts [4]:

- A part that contains simulation scheme.
- Another part is dedicated to information area.
- The third part is the area where is dynamically getting up the waveforms characteristic to the switch controller analyzed.
- According to the manner of the scheme, choose the type of the single-phase AC switch controller, which can be with two thyristors, with one thyristor, or with one thyristor in diagonal of a diode bridge (**Figure 11**) [5].

In the laboratory classes, students choose the type of the switch controller, making different simulations to understand the principle of operation in each case. During the simulation, besides information in the text, the teacher explains what happens in each case.

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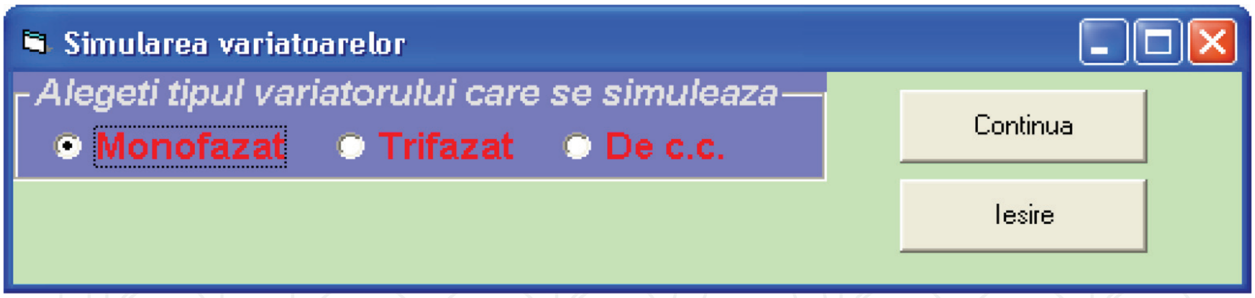

Figure 9. The main simulation window of the switch controllers.

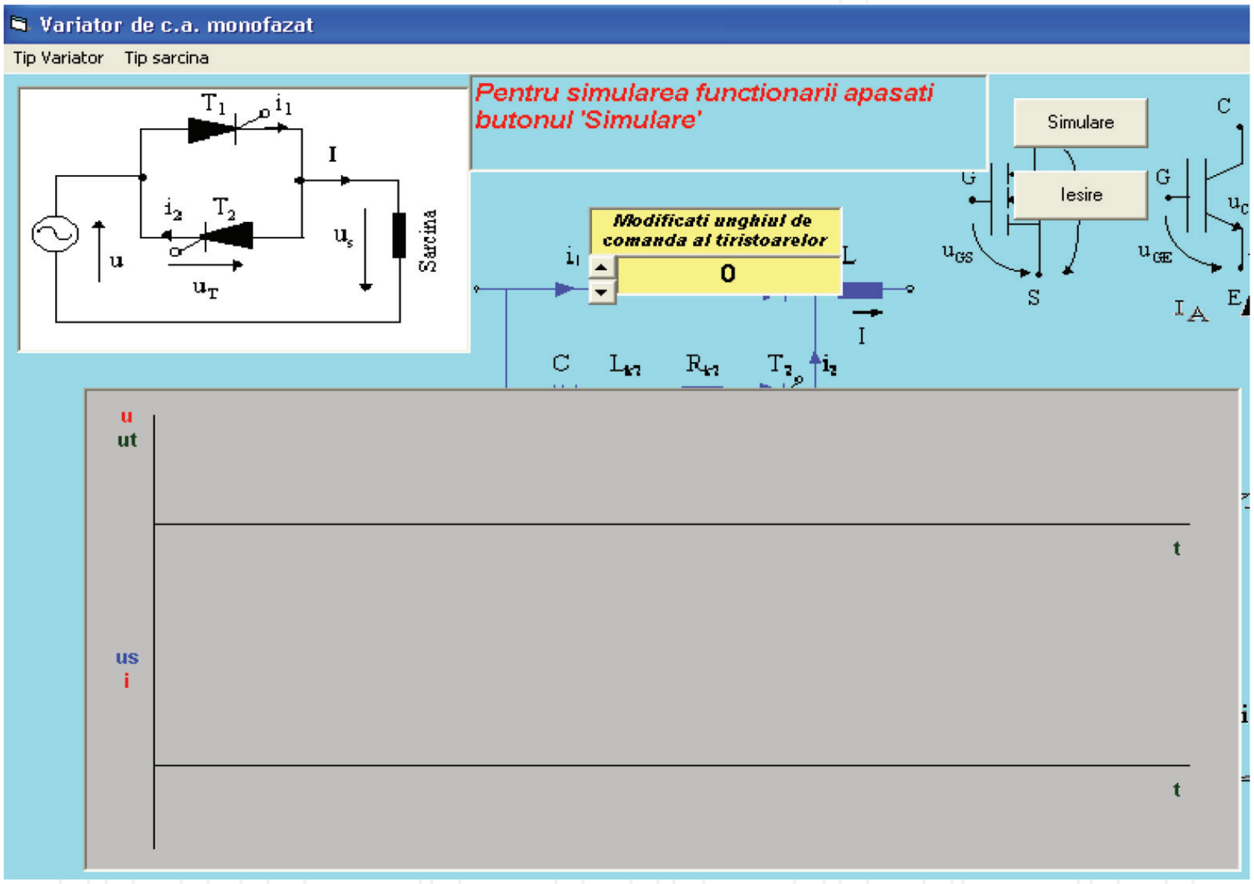

Figure 10. The simulation window of the single-phase AC switch controller.

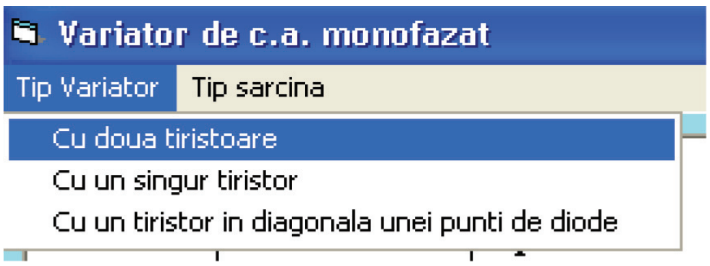

Figure 11. Choosing the single-phase AC switch controller type.

- It chooses the single-phase AC switch controller type (e.g., single-phase AC switch controller with two thyristors) (**Figure 12**).
- It chooses the load type which can be resistive, inductive, or resistive-inductive (**Figure 13**) [7].

The range of variation of the single-phase converter phase angle and the current variation depends on the type of load. To observe the differences in the different tasks, in laboratory classes are being analyzed converter function with resistive, inductive, or resistive-inductive loads, and is being drawn conclusions about the current variation. During the simulation, the students change the command angle to observe the modification of the RMS voltage and current.

- The command angle may be modified using up/down arrows, being shown their values. Along the simulation, it modified the command angle of the switch controller, in order to evidence the way of voltage modification, or the current through load (**Figure 14**).

Notes

It may choose any load type in combination with any switch controller types.

The command angle of the thyristors may vary between 90° and 180°, in the case choosing an inductive load (**Figure 15**).

In the case of choosing a resistive-inductive load, the command angle of the thyristors depends on the value that we want to establish by introducing a delay angle, changing the command angle of the thyristors being made from that value in up (**Figure 16**) [5].

In all three cases, if the command angle changes below or above the permissible values, the program alerts the user by an error message (**Figure 17**).

- It launches in running the single-phase AC switch controllers with two thyristors, with the control button (Simulare), which is then converted to the simulation stop button (Stop), which is located on the top right (**Figure 18**).
- During the simulation, the scheme dynamically changes its color, the sides what are in conduction at a time (**Figure 19**).
- It will follow the area in which text information about the function mode of the single-phase AC switch controllers are presented (semiconductor elements that are in conduction, semiconductor elements direct polarized, etc.) (**Figure 20**).
- Is watching the area in which is rises dynamically the characteristic waveforms of the single-phase AC switch controllers **Figure 21**.
- It is observed that by changing the command angle α between zero and π, the current by resistive load varies between maximum value U/R and zero. In the case of inductive load, because the current by load is a lag behind with $\pi/2$, the command angle can be varied by interval $[\pi/2, \pi]$, and in the case of resistive-inductive, the command angle varies between ϕ and π.

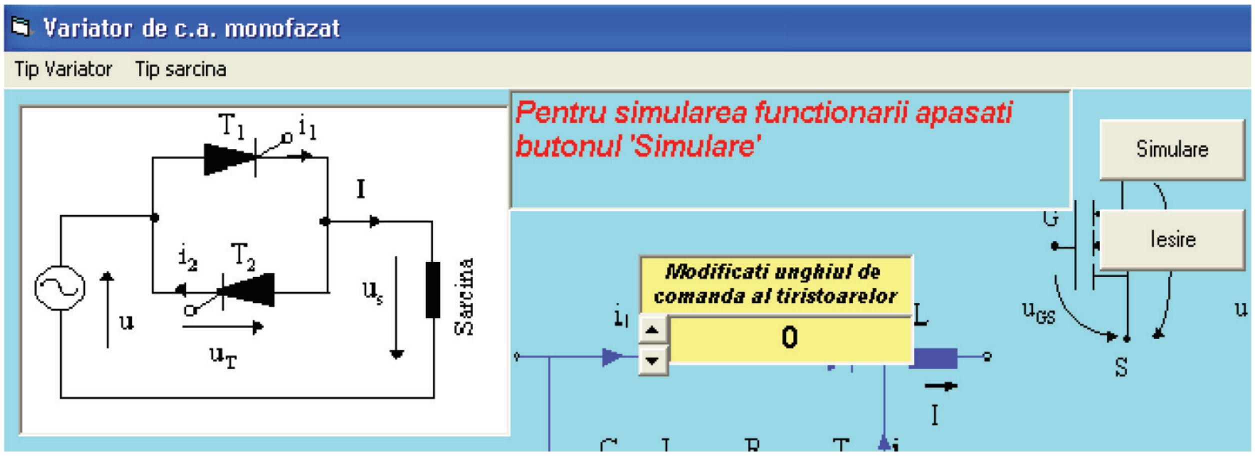

Figure 12. The single-phase AC switch controller window.

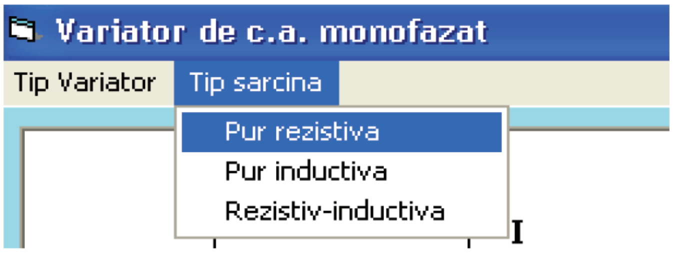

Figure 13. Choosing the load type.

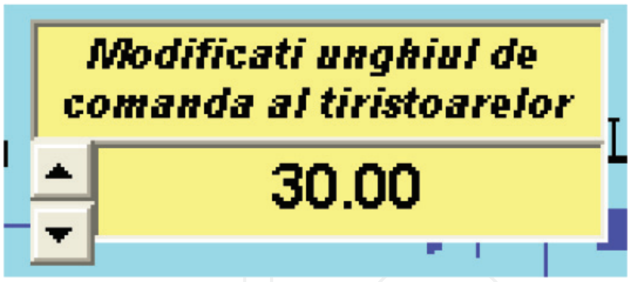

Figure 14. Changing command angle in case of single phase switch controller.

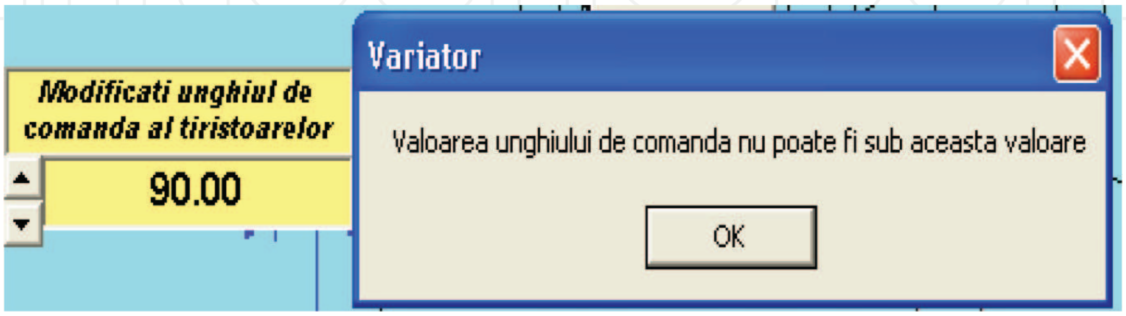

Figure 15. The error message in the case an inductive load.

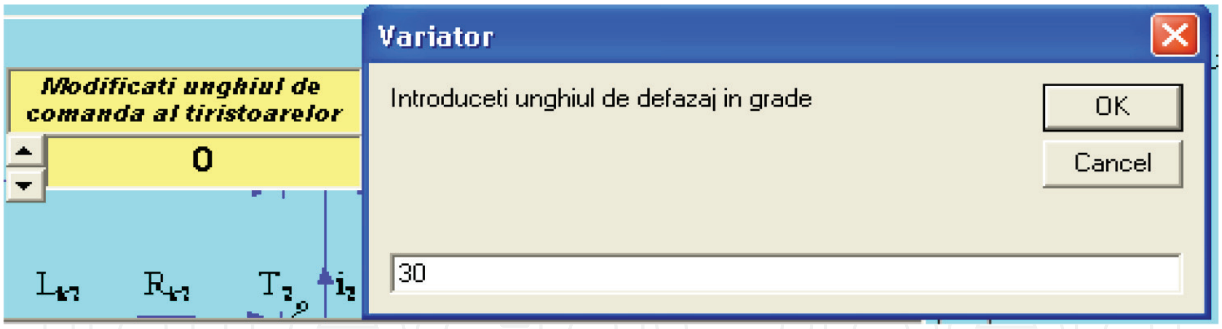

Figure 16. The changing of command angle in the case resistive-inductive load.

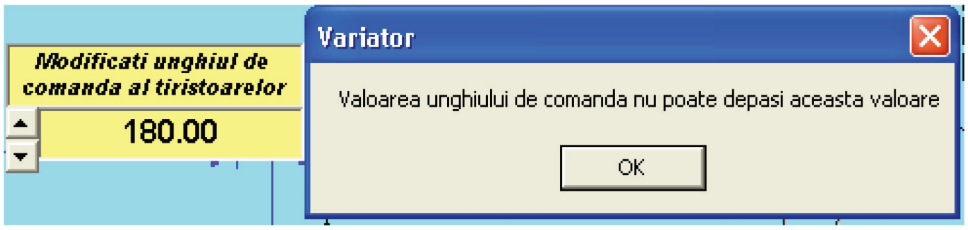

Figure 17. The error message.

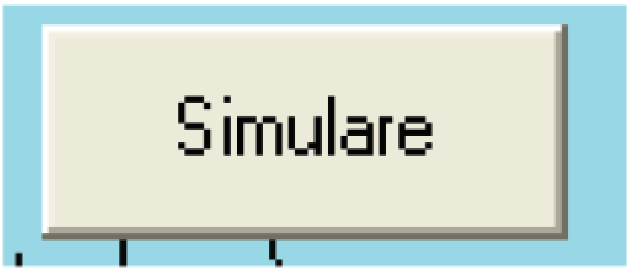

Figure 18. The control button (Simulare) in case of single phase switch controller.

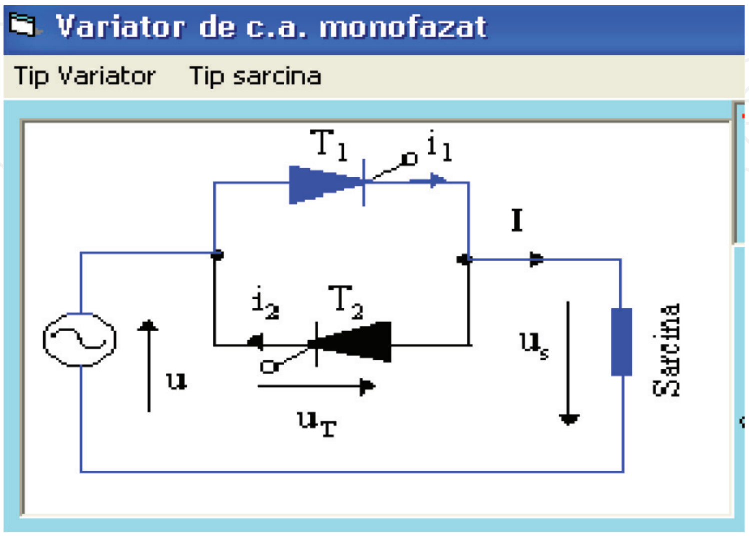

Figure 19. Simulation scheme in case of single phase switch controller.

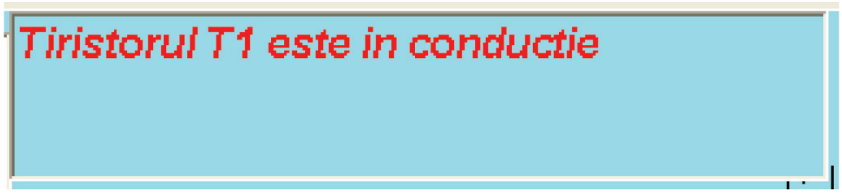

Figure 20. The information area of text type in case of single phase switch controller.

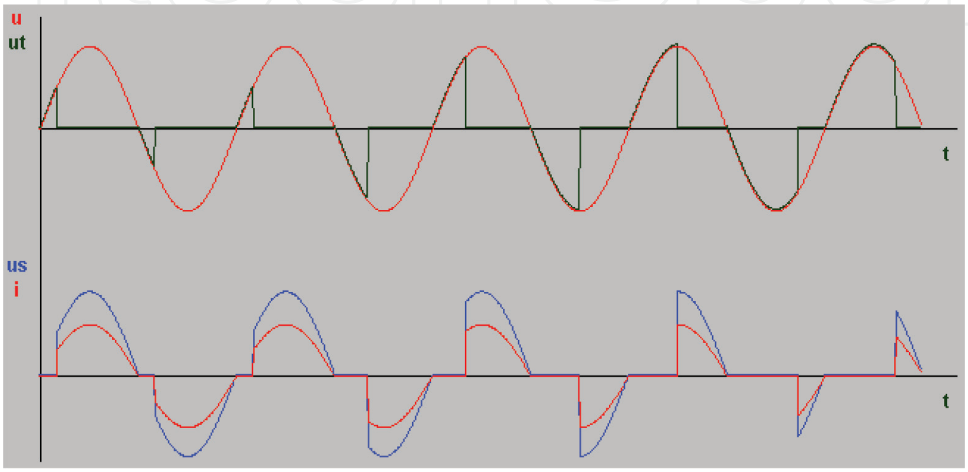

Figure 21. The waveforms area for the single-phase AC switch controllers with resistive load.

For the three-phase AC switch controller, simulation is opening the window as shown in **Figure 22**.

And to the three-phase AC switch controller, the simulation windows are three main part formats from the first part which contains simulation scheme, the second part is dedicated to information area, and the third part is the area where is dynamically getting up the waveforms characteristic to the switch controller analyzed [5].

- Choose the type of the three-phase AC switch controller, which can be with two thyristors on phase, with one thyristor and one diode on the phase (**Figure 23**).
- The command angle may be modified using up/down arrows, being shown their values. Along the simulation, it modified the command angle of the three-phase AC switch controller with two thyristors on the phase, in order to evidence the way of voltage modification, or the current through load (**Figure 24**).
- It launches in running the single-phase AC switch controllers with two thyristors, with the control button (Simulare), which is then converted to the simulation stop button (Stop), which is located on the top right (**Figure 25**).
- During the simulation, the scheme dynamically changes its color, the sides what are in conduction at a time (**Figure 26**) [6].

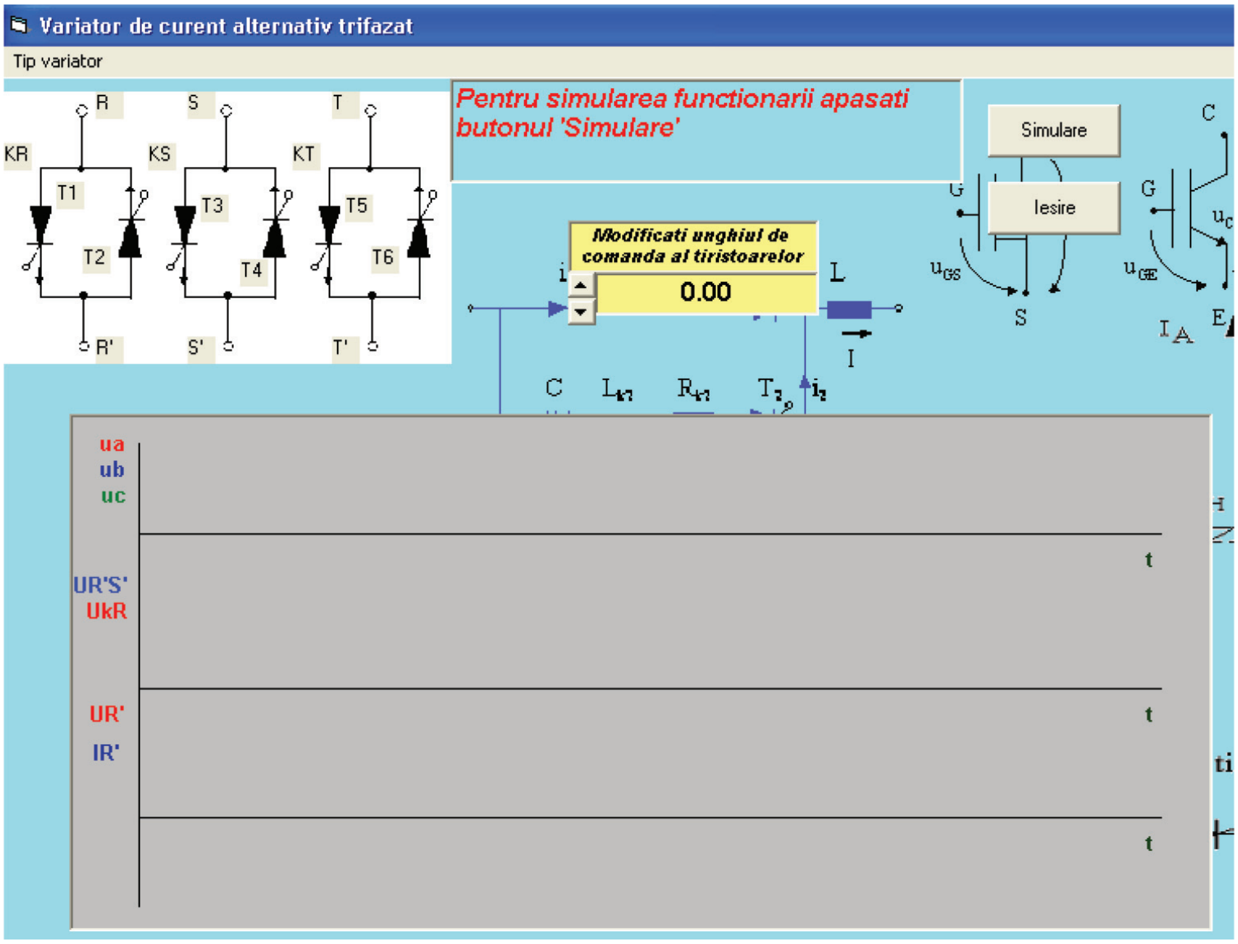

Figure 22. The simulation windows of the three-phase AC switch controller.

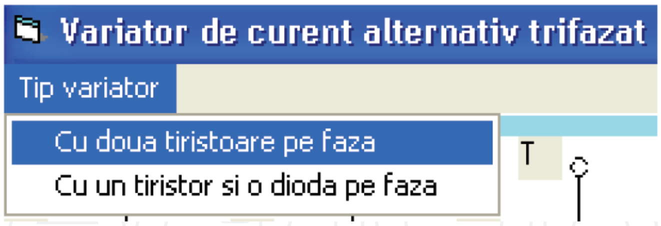

Figure 23. Choosing the three-phase AC switch controller type.

Figure 24. Changing command angle in case of thre-phase switch controller.

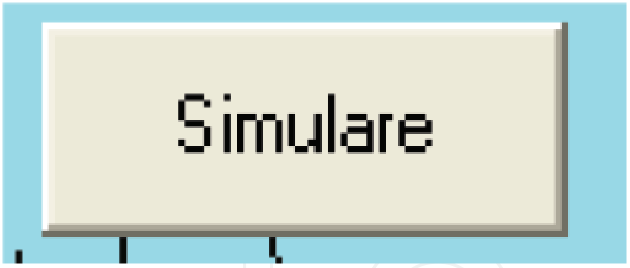

Figure 25. The control button (Simulare) in case of thre-phase switch controller.

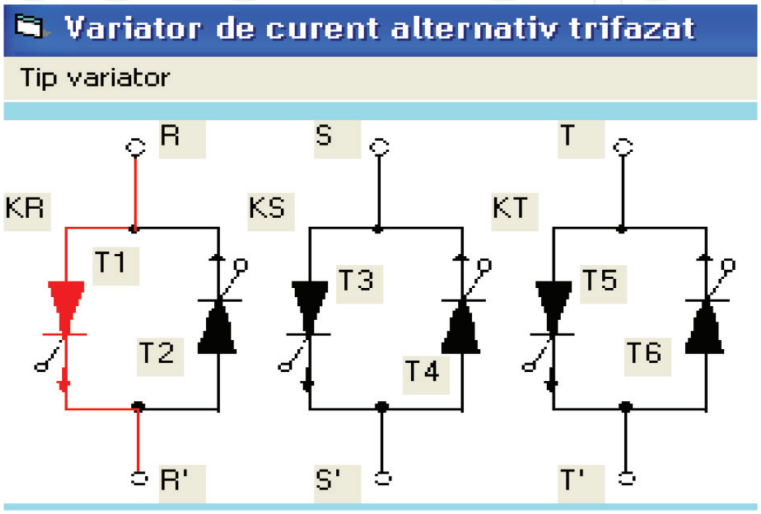

Figure 26. Simulation scheme in case of thre-phase switch controller.

- It will follow the area in which text information about the function mode of the three-phase AC switch controllers are presented (semiconductor elements that are in conduction, semiconductor elements direct polarized, etc.) (**Figure 27**).
- Is watching the area in which is rises dynamically the characteristic waveforms of the three-phase AC switch controllers (**Figure 28**).

The simulation of three-phase switch controller is made for different types of load and by changing the angle of the semiconductor elements. Based on information from the simulation, the students made a report on the functioning in different cases, which is then analyzed together with the teacher, being clarified with aspects of the operating principle.

Figure 27. The information area of text type in case of thre-phase switch controller.

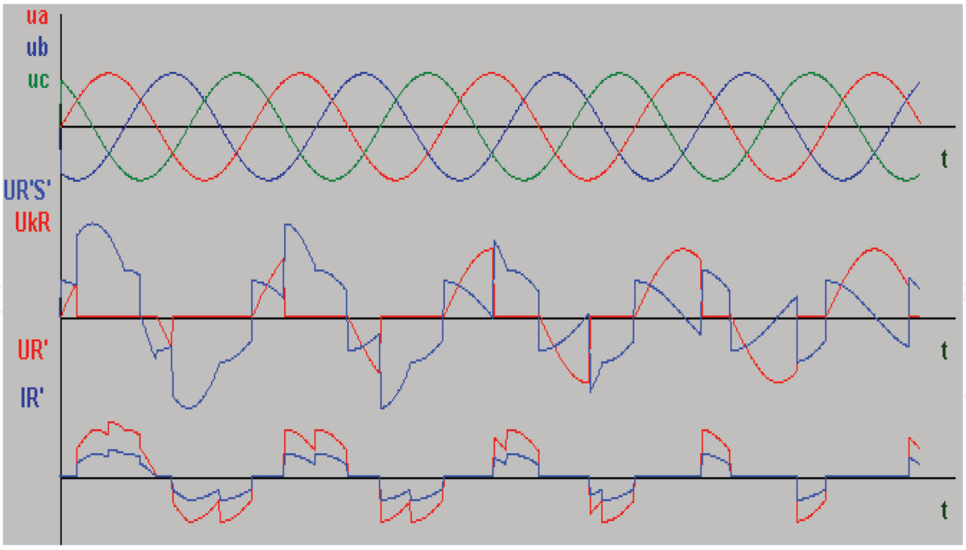

Figure 28. The waveforms area for the three-phase AC switch controllers with resistive load.

- In the resistive load case, the angle ignition variation to the thyristors is comprised between zero and π, the thyristors of K_R being in conduction on period $\alpha \div \pi$, for the positive semi-alternate and $\pi + \alpha \div 2\pi$ for the negative alternate.
- At the end of simulation is pressed the button (Iesire) for application exit, after that is being able to choose, from the main simulation window, another simulation to run (**Figure 29**).

Figure 29. The button for application exit (Iesire).

4. Conclusions

In electrical devices, the AC switch controller is used for asynchronous motor speed change by changing the supply voltage and to the asynchronous motor startup by varying the voltage between zero and nominal value.

These types of static converters are used to control the voltage applied to the stator windings of a cage induction motor or to modify the effective rotor resistance of a wound induction motor. In first case, the converter is connected in series with the stator windings, and in second case in parallel with a resistance.

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Using an AC switch controller is the simplest way to control the speed of AC drive systems. However, this method has some disadvantages such as low input power factor, decreasing efficiency with lower speeds, increasing losses of a drive system if the converter used modifies the effective rotor resistance.

The simulation scheme dynamically changes its color, the sides what are in conduction at a time. In the simulation window, there is a text area where information about the function mode of the converter, the semiconductor elements direct polarized or which are in conduction at that moment are displayed. The window contains also an area with buttons for changing the command angle.

Some of the simulation windows contain a pull-down menu button used to change some parameters or to choose different types of loads. All windows contain two command buttons, one for starting up the simulation (Simulare), which is transformed in button for stop the simulation (Stop) and a button to exit of the window (Iesire).

This documentation describes a Windows application, useful for understanding the functioning of the static variators, converters, and typing to cover all the needed aspects. This application has a teaching purpose, being useful for the students studying static converters.

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