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Zbornik radova sa XXI međunarodnog naučno - stručnog skupa
INFORMACIONE TEHNOLOGIJE - sadašnjost i budućnost
održanog na Žabljaku od 29. februara do 05. marta 2016. godine

Zbornik radova
INFORMACIONE TEHNOLOGIJE - sadašnjost i budućnost 2016

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Tiraž
150

Podgorica 2016.

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Elektrotehnički fakultet, Univerzitet Crne Gore

Suorganizatori:
BIO-ICT Centar izvrsnosti

Skup su podržali:
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Ministarstvo nauke

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PRIMENA PROGRAMSKOG PAKETA PSIM U SIMULACIJI ENERGETSKIH PRETVARAČA
APPLICATION OF SOFTWARE PSIM IN SIMULATION OF POWER CONVERTERS

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Sadržaj: *Rad prikazuje primenu softverskog paketa PSIM koji omogučava simulaciju rada energetskih pretvarača i na taj način zamenjuje skupu labaratorisku opremu. Razrađeni su dva primera energetskh pretvarača i to trofazni kontrolisani ispravljač i trofazni invertor kao elektronski sklopovi koji imaju široku primenu u praksi. Upoređeni su teoretski dobijeni rezultati ulaznih i izlanih napona iz svakog tipa pretvarača i naponi dobijeni pomoću simulacije. Na osnovi toga izvedeni su zaključci o uspešnosti primene softverskog paketa PSIM u simulacii rada energetskih pretvarača kao pomoćnog sredstva u laboratorijskim vežbama.*

Abstract: *Paper presents application of software PSIM in simulation of operation of power converters as an replacement of expensive laboratory equipment. Two different examples are worked out in the paper. First one is a three phase controlled bridge rectifier and the second one is three phase inverter , both chosen as a result of their wide practical application. A comparison between theoretical results of input and output voltages from the converters and from the simulation is presented. Based on the comparison conclusions are made about the success of the application of PSIM in simulation of power converters as an auxiliary tool in laboratory exercises.*

1. INTRODUCTION

Power converters have wide application in electrical industry but as well as in every-day life. They are used in battery chargers of many electronic devices, in lightening, in uninterruptible power supplies (UPS) but as well as in more sophisticated applications such as controlled electrical drives with adjustable speed of operation [1]-[3]. They provide the desired electrical parameters of the power supply (form of the voltage: DC or AC, the amplitude and the frequency). Understanding their principles of operation is very important for their proper usage. Simulation software is often used as an adequate replacement of an expensive laboratory equipment enabling the choice of adequate electronic components, their connections in the scheme of the power converter, adequate setting and triggering of electronic components and finally obtaining the waveforms of input and output voltage[4]-[5]. This philosophy is applied in analysis and simulation of power converter circuits analyzed as part of undergraduate course of power converters within Faculty of Electrical Engineering at University "Goce Delcev". Original simulation models of different types of converters are developed in simulation software PSIM. The software itself offers broad possibilities for analysis of different types of electronic circuits due to its extensive library of electronic components and their controlling circuits. The user friendly interface enables quick and easy creation of electronic circuits and evaluation of obtained results without any prior knowledge of the software itself or any programming experience compared to other simulation software like Matlab or Simulnik. In this paper two different types of power converters are analyzed. First one is three phase controlled bridge rectifier often used as industrial rectifier in numerous electrical facilities where DC voltage is need as an auxiliary voltage for signaling and command purposes. The second one is a three phase inverter often used in three phase UPS applications, as a part of electricity production from solar panels or in the adjustable speed drives. Theoretical bases of both power converters are presented together with their principle of operation, basic equations and waveforms of input and output voltages. Creation of electrical scheme is explained together with the controlling scheme of electronic components. On the oscilloscope are recorded input and output waveforms and they are compared with theoretical results.

2. PRINCPLE OF OPERATION

2.1. THREE-PHASE CONTROLLED BRIDGE RECTIFIER

Most of the bridge schemes of power converter use six electronic components (diodes, thyristors or transistor) most often three of them connected in the upper part of the bridge and three in the lower part of the bridge (Fig.1). In order to have rectified output voltage one electronic component from upper part of the bridge is in the conducting state or ON state and one from the lower part of the bridge. For example in our case must be simultaneously in ON position the thyristors T1 and T2, than T3 and T2, than T3 and T4 etc.. As the name indicates the power supply on the input of the rectifier is three phase symmetrical power supply with line voltages 380 V, and supply frequency of 50 Hz.

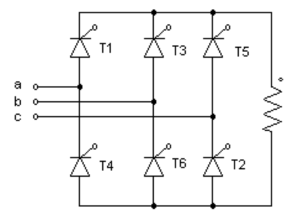

Fig.1 Electrical connection of three-phase rectifier

The line input voltages are presented in Fig. 2 a. Since the bridge is controlled which means that mean and rms value of the output voltage can be controlled the electronic components used in the rectifier are thyristors which are switched on only when the control signal is applied on the gate of the thyristor and when voltage on its anode is higher than the voltage on the cathode. This means that by controlling the moment when the thyristors are switched on , i.e. the angle of the input voltage for which the thyristor are switched on-α, the output voltage, its mean and rms value is controled as well [6].

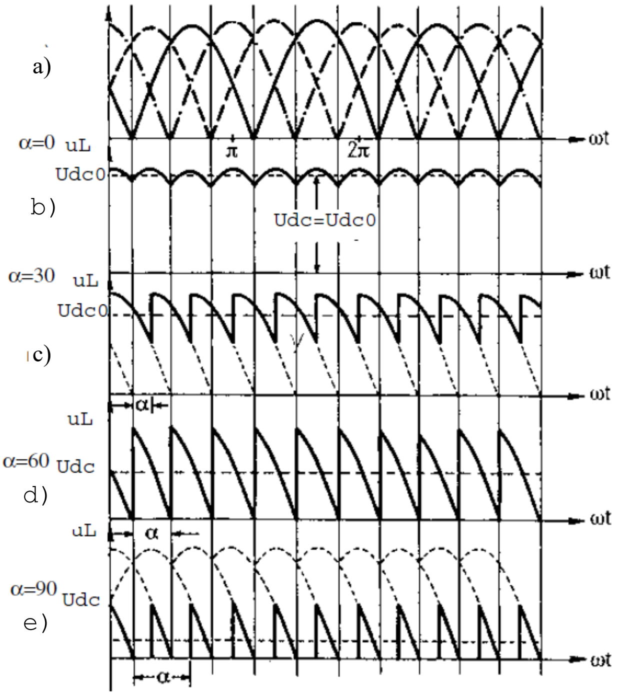

Fig. 2 Input and output voltage waveforms from rectifier

Two operational regimes of the rectifier are distinguished. When control angle (α) of the thyristors is within the range 0º-60º rectifier is working in the continuous current mode. When control angle is increased within the range 60º-120º rectifier is operating in the discontinuous current mode.

Mean value of the rectified voltage on the load side for $0^0 \le \alpha \le 60^0$ is:

$$U_{dc\alpha} = \frac{3}{\pi} \int_{\alpha+30^0}^{\alpha+90^0} \sqrt{3} U_m \sin\left(\omega t + 30^0\right) d\omega t \qquad (1)$$

$$= \frac{3\sqrt{3}}{\pi} U_m \cos\alpha = U_{dc01} \cos\alpha$$

Where U_{dc01} is the mean value of rectified voltage on load side when control angle α=0.

For interval $60^0 \le \alpha \le 120^0$ the mean value of load voltage is:

$$U_{dc\alpha} = \frac{3\sqrt{3}}{\pi} U_m \left[1 + \cos\left(\alpha + 60^0\right)\right] \qquad (2)$$

Rms value of the output voltage for both operation modes of the converter is:

$0^0 \le \alpha \le 60^0$

$$U_L = \frac{\sqrt{3} U_m}{2} \sqrt{\frac{2\pi + 3\sqrt{3}\cos 2\alpha}{\pi}} \qquad (3)$$

$60^0 \le \alpha \le 120^0$

$$U_L = \frac{\sqrt{3} U_m}{2} \sqrt{\frac{4\pi - 6\alpha - 3\sin\left(2\alpha - 60^0\right)}{\pi}} \qquad (4)$$

Operation of the rectifier and output waveforms are presented for active load (resistance).

2.2. THREE-PHASE INVERTER

Three phase inverters enable transformation of DC voltage to AC with adjustable amplitude and frequency of output voltage. As well as the bridge rectifiers three phase invertors operate in bridge connection with six controlled electronic components (thyristors or transistor).

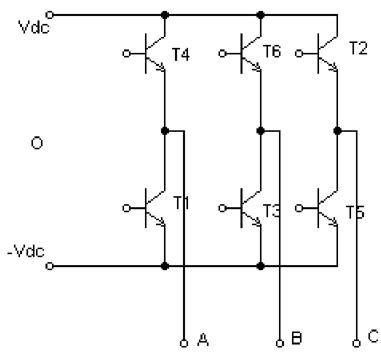

Fig.3 Three-phase inverter

Simultaneously are switch on one transistor from the upper part of the bridge and one from the lower part. The output phase voltages U_{AN}, U_{BN} and U_{CN} as well as the line voltage U_{AB} are presented in Fig.4 [6].

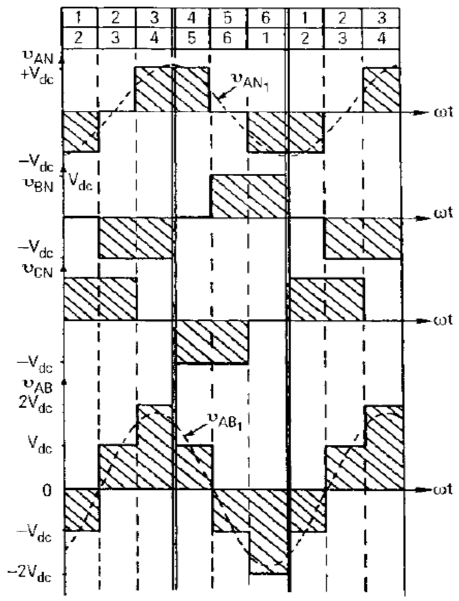

Fig.4 Output waveforms from the inverter

Output waveforms of the voltage in Fig.4 are presented for operation of the voltage inverter at no-load. But the output waveforms in case of no-load and connected resistive load to A,B,C, connection from Fig. 3 are identical. So following equations are valid:

0°<ωt< 60°

$$u_{AN} = -I_L R = -\frac{2V_{dc}}{2R}R = -V_{dc} \quad (5)$$

$$u_{BN} = 0 \quad (6)$$

$$u_{CN} = I_L R = \frac{2V_{dc}}{2R}R = +V_{dc} \quad (7)$$

$$u_{AB} = u_{AN} + u_{NB} = u_{AN} - u_{BN} = -V_{dc} \quad (8)$$

60°<ωt< 120°

$$u_{AN} = 0 \quad (9)$$

$$u_{BN} = -I_L R = -V_{dc} \quad (10)$$

$$u_{CN} = I_L R = V_{dc} \quad (11)$$

$$u_{AB} = V_{dc} \quad (12)$$

120°<ωt< 180°

$$u_{AN} = I_L R = V_{dc} \quad (13)$$

$$u_{BN} = -I_L R = -V_{dc} \quad (14)$$

$$u_{CN} = 0 \quad (15)$$

$$u_{AB} = 2V_{dc} \quad (16)$$

3. SIMULATION MODELS

3.1. THREE-PHASE CONTROLLED BRIDGE RECTIFIER

Simulation package PSIM and its student version offer sufficient number of elements for simulation of electronic or electrical circuits. In this case it will be used for creation of electronic circuits of power converters described above. In case of three-phase controlled rectifier all electronic elements (thyristors) are connected according to the Fig.1. Three-phase symmetrical power supply is connected on the input of the rectifier. Operation of thyristors is controlled by their gates. From the other hand, gates are controlled by series of pulses connected to them (Fig. 5). Sequence of operation of thyristors is presented in Table.1 The angle of switching on of thyristors is 30°.

Table 1. Sequence of operation of thyristors at rectifier

Thyristor	Switching angles
T1	60 70. 120 130.
T2	120 130. 180 190.
T3	180 190. 240 250.
T4	240 250. 300 310.
T5	300 310. 360 370.
T6	60 70. 360 370.

Input and output voltages from the rectifier are presented in Fig. 5.

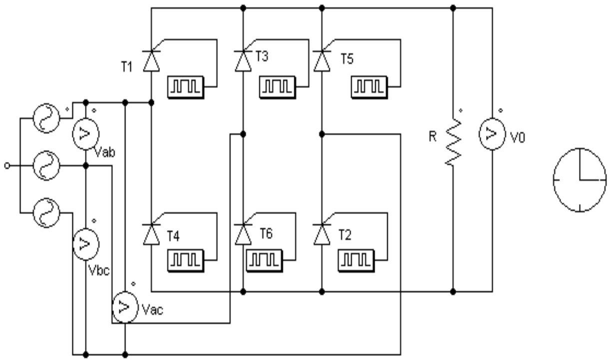

Fig.5 Simulation model of the rectifier

The simulation time is controlled and adjusted via the clock (Fig.5). Adequate voltmeters are connected on input and output side of the rectifier in order input line voltages U_{ab}, U_{ac} and U_{bc} to be measured as well as output voltage U_o.

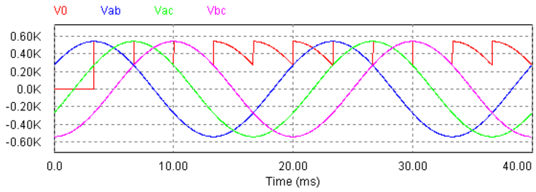

Fig.6 Waveforms of input and output voltage from rectifier

3.2. THREE-PHASE INVERTER

Simulation model of three-phase voltage inverter is based on electrical scheme from Fig.3. Input DC voltage is transformed into AC rectangular voltage waveforms by implementing the adequate sequence of operation of transistors (Table 2). The amplitude of the input voltages is 200 V.

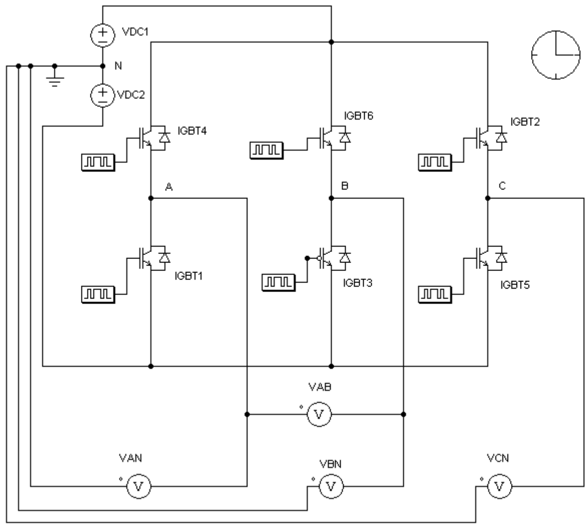

Fig.7 Simulation model of the inverter

As electronic switches are used IGBT transistors controlled by the pulse signal applied on their gates.

Table 2. Sequence of operation of transistors at inverter

Transistor	Sequence of operation
IGBT1	0 60. 300 360
IGBT2	0 60. 60 120.
IGBT3	60 120. 120 180.
IGBT4	120 180. 180 240.
IGBT5	180 240. 240 300
IGBT6	240 300. 300 360

Output phase voltages U_{AN},U_{BN} and U_{CN} are presented in Figs. 8,9 and 10 consecutively. The line voltage U_{AB} is presented in Fig. 11.

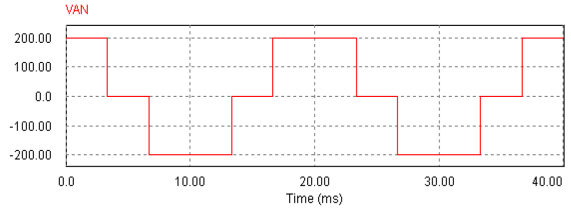

Fig.8 Output phase voltage U_{AN} from the inverter

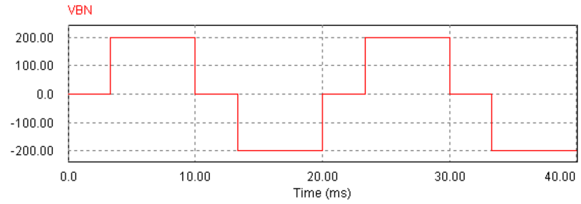

Fig.9 Output phase voltage U_{BN} from the inverter

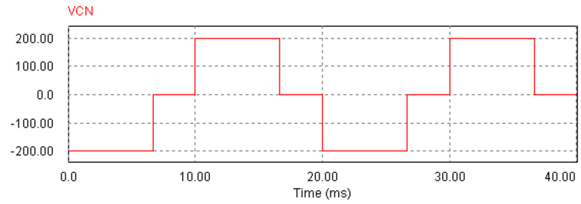

Fig.10 Output phase voltage U_{CN} from the inverter

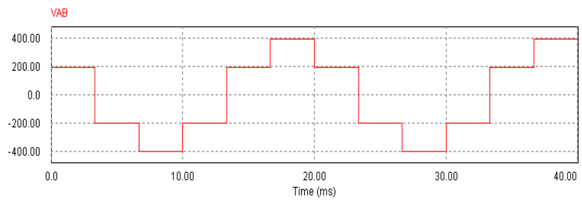

Fig. 11 Output line voltage U_{AB} from the inverter

From comparison of presented results from Fig. 2 c) and Fig. 6 it is evident the similarity of output voltage waveforms in case of three-phase controlled bridge rectifier when switching angle of thyristors is 30 °. The presented results of output line voltage from the simulation model of the inverter (Fig. 8, 9 and 10) are adequate to the presented theoretical result (Fig.4). Output voltage from the inverter (Fig.11) is in complete agreement with Fig.4 and (5)÷(16). Therefore it can be concluded that software PSIM is modelling the power converters with satisfactory accuracy and it enables overview of the basic principles of their operation

4. CONCLUSION

Power converters are widely used electronic devices in application where transformation of voltage parameters such as waveform, amplitude or frequency is necessary. Online recording of input and output voltage of the converters often requires expensive equipment. Therefore for the purpose of laboratory exercises for the students, software PSIM is introduced as a replacement. Paper has presented the simulation models of two types of converters and has proved that for basic understanding of principle of operation of power converters student version of software PSIM is operating satisfactorily. More complex models of power converters requires more complex control circuits and adequate filters which can be modelled by advanced versions of the software and used in professional design of power converters.

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