SYSTEM ENGINEERING, COMPUTER TECHNOLOGY

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SISTEMŲ INŽINERIJA, KOMPIUTERINĖS TECHNOLOGIJOS

Application of Simulation Packages in Classes of Switching Converters

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Introduction

Switching technologies are applied for obtaining some specific tasks in power electronics. Simplest of SC are DC/DC converters of Buck and Boost mode. Its operation is characterised with switching frequency f and duty ratio D. On Fig. 1 a scheme of Buck converter is presented, where switch is presented by IGBT transistor. This scheme is characterised with main equations obtained by linearization as follows:

Mean value of load voltage

$$U_{lda} = U_d . D .$$

Mean value of load current

$$I_{lda} = U_{lda} / R .$$

Mean value of supply current

$$I_{sa} = D.I_{lda} .$$

Full deviation of load's current

$$\Delta I_{Ld} = \frac{U_d D(1-D)}{L_{ld} f} .$$

Full deviation of input filter's capacitor voltage

$$\Delta U_{cf} = \frac{I_{lda} D(1-D)}{C_f f} .$$

Full deviation of supply current

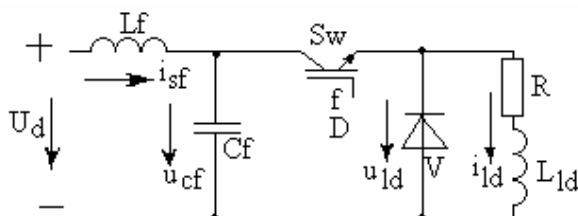$$\Delta I_{sf} = \frac{\Delta U_{cf}}{8 L_f f} .$$

Fig. 1. Scheme of Buck converter

Changing duty ratio in range from 0 till 1 it is possible to adjust necessary mean value of load's voltage and current.

In result of simulation the scheme Fig. 1 with parameters U_d=100 V, D=0.4, f=1kHz, R=2 Ω, L=10 mH was obtained a diagrams presented on Fig. 2 and meanings of parameters presented in Table 1.
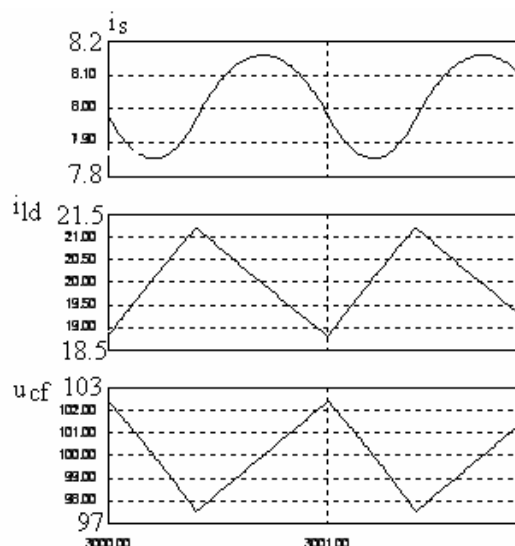

Fig. 2. Simulated diagrams of the scheme Fig. 1

Table 1. Experimental results

Meaning	Unit	Experiment	Calcul.
U_{lda}	V	40	40
I_{lda}	A	20	20
I_{sa}	A	8.0	8.0
ΔI_{ld}	A	2.32	2.4
ΔU_{cf}	V	4.7	4.8
ΔI_{sf}	A	0.31	0.3

The next basic scheme of switching converter is BOOST scheme presented on Fig. 3. This scheme is

characterized with obtained by linearization equations as follows:

Mean value of load voltage

$$U_{lda} = \frac{E_1 R_2 (1-D)}{R_2 (1-D)^2 + R_i}.$$

Mean value of load current

$$I_{lda} = \frac{U_{lda}}{R_2}.$$

Mean value of supply current

$$I_{sa} = \frac{I_{lda}}{1-D}.$$

Full deviation of supply current

$$\Delta I_s = \frac{(E_1 - I_{sa} R_i)D}{L_1 f}.$$

Full deviation of capacitor voltage

$$\Delta U_{cf} = \frac{I_{lda} D}{fC}.$$

Full deviation of loads current
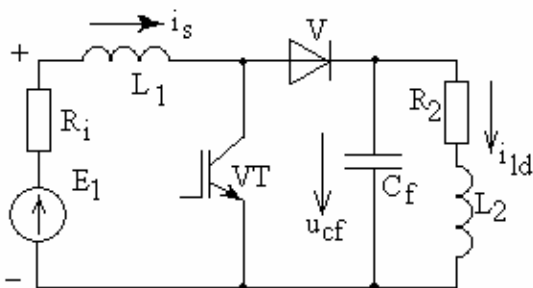
$$\Delta I_{ld} = \frac{\Delta U_{cf}}{8 L_2 f}.$$

Fig. 3. Scheme of BOOST converter

In result of simulation the scheme with parameters E_1=100 V, R_i=0.1 Ω, L_1=10 mH, C=1000μF, L_2=5 mH, R_2=10 Ω, D=0.4, f=1 kHz was obtained a diagrams presented on Fig. 4 and meanings of parameters presented in Table 2.

Table 2. Experimental results

Meaning	Unit	Experiment	Calcul.
U_{lda}	V	162.1	162.16
I_{lda}	A	16.21	16.16
I_{sa}	A	27.0	27.03
ΔI_s	A	4.0	3.89
ΔU_{cf}	V	6.2	6.49
ΔI_{ld}	A	0.15	0.16

As can be it seen calculated and experimental values are very close that allows to accept calculation methodology as appropriate.
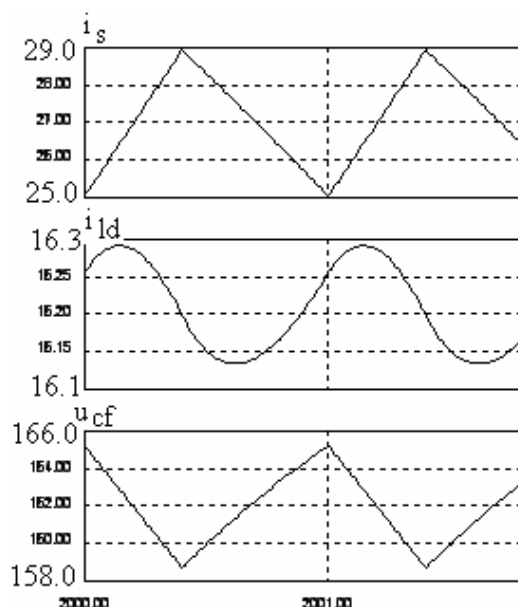

Fig. 4. Simulated diagrams for BOOST converter

Switching converters with sinus shape output current

Very often switching converters are applied for obtaining a sinus shape of load current. Usually for control a bipolar symmetric saw tooth mode voltage u_{st} with magnitude U_{stm} and frequency f_s is compared with a sinus shape control voltage u_{co} with magnitude U_{com} and frequency f_{co} which is much smaller than frequency of saw-tooth voltage (Fig. 5).

One of simplest is scheme of bridge with DC input and AC output by fundamental components of voltage and current obtained by switching on transistors VT1,VT2 when $u_{co} > u_{st}$ and switching on transistors VT3,VT4 when $u_{co} < u_{st}$ presented on Fig. 5.
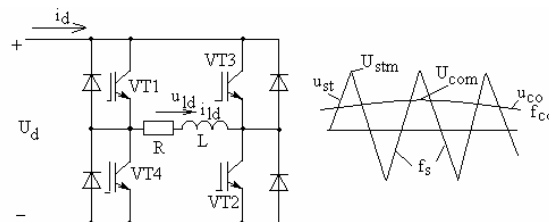

Fig. 5. Scheme of switching single-phase DC/AC converter and its control

For this scheme simplified equations can be presented as follows:

Magnitude value of the fundamental of output voltage

$$U_{ldm} = U_d \frac{U_{com}}{U_{stm}}.$$

RMS value of output voltage

$$U_{lde} = \frac{U_{ldm}}{\sqrt{2}} .$$

RMS value of load current

$$I_{lde} = \frac{U_{lde}}{\sqrt{R^2 + (2\pi f_{co}L)^2}} .$$

Mean value of the input current

$$I_{da} = \frac{U_d U_{com}^2 R}{2U_{stm}^2 [R^2 + (2\pi f_{co}L)^2]} .$$

Fundamental curve of load's current

$$i_{ldf} = \sqrt{2}I_{lde} \sin(2\pi f_{co}t - \varphi),$$

$$\varphi = arctg \frac{2\pi f_{co}L}{R} .$$

Full deviation of load's current

$$\Delta I_{ld} = \frac{[U_d - RI_{ldm} \sin(2\pi f_{co}t - \varphi)]}{2Lf_s} x$$

$$x(1 + \frac{U_{com} \sin 2\pi f_{co}t}{U_{stm}}).$$

Main simulated diagrams of currents for the scheme on Fig. 5 at U_d=100 V, R=2 Ω, L=10 mH, f_s=5 kHz, f_{co}=50 Hz, U_{stm}=15 V, U_{com}=5 V are presented on Fig. 6, but main values of parameters as calculated as well simulated are presented in Table 3.

Table 3. Experimental results

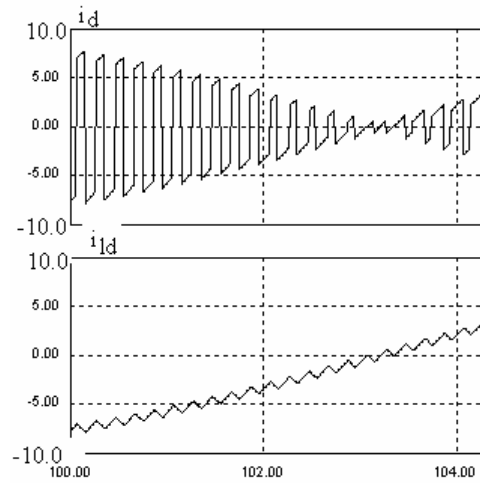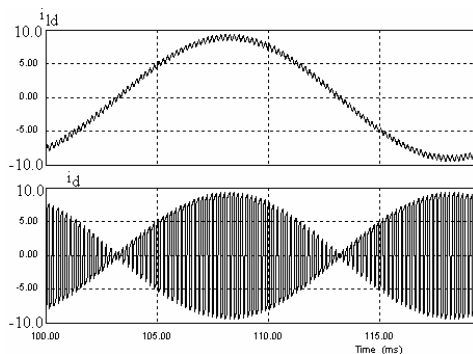| Meanings	Unit	Simulated	Calcul.
U_{ldm}	V	33.4	33.3
U_{lde}	V	23.5	23.45
I_{lde}	A	6.35	6.3
I_{ldm}	A	8.95	8.94
I_{da}	A	0.797	0.8
φ	^{0}el	59.4	57.5
ΔI_{ld} at $\omega_{co}t= \varphi$	A	1.15	1.2

Fig. 6. Diagrams of currents for scheme Fig. 5

The next scheme simulated is one of DC-three phase output with bridge converter controlled by PWM mode realized by comparison of the bidirectional symmetric saw tooth voltage with three shifted mutual with 120^0 sinus shape control voltages. When instantaneous value of control voltage is bigger than a saw-tooth one then upper transistor is switched on but otherwise – a lower transistor. Scheme of converter is presented on Fig. 7.
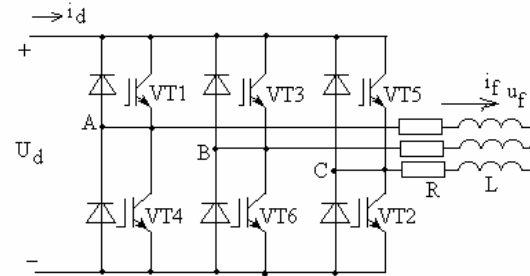

Fig. 7. Scheme of the DC-three phase AC converter

For this scheme at PWM control main parameters can be calculated as follows:
Magnitude of fundamental of phase voltage

$$U_{phm} = 0,5.U_d \frac{U_{com}}{U_{stm}} .$$

RMS value of phase voltage

$$U_{phe} = \frac{U_{phm}}{\sqrt{2}} .$$

RMS of phase current

$$I_{phe} = \frac{U_{phe}}{\sqrt{R^2 + (2\pi f_{co}L)^2}} .$$

Mean value of input current

$$I_{da} = \frac{3I_{phe}{}^2 R}{U_d} .$$

Phase shift angle for load's current and voltage

$$\varphi = arctg \frac{2\pi f_{co} L}{R} .$$

Full deviation of load's current

$$\Delta I_{ph} = \frac{[0.5 U_d - R I_{phm} \sin(2\pi f_{co} t - \varphi)}{2 L f_s} x$$

$$x(1 + \frac{U_{com}}{U_{stm}} \sin 2\pi f_{co} t).$$

Diagrams of phase current and input current are presented on Fig. 8, but main parameters measured and calculated are presented in Table 4. Examinations was done for U_d=200 V, U_{stm}=15 V, U_{com}=5 V, f_{co}=50 Hz, f_s=5 kHz, R=5 Ω, L=5 mH.
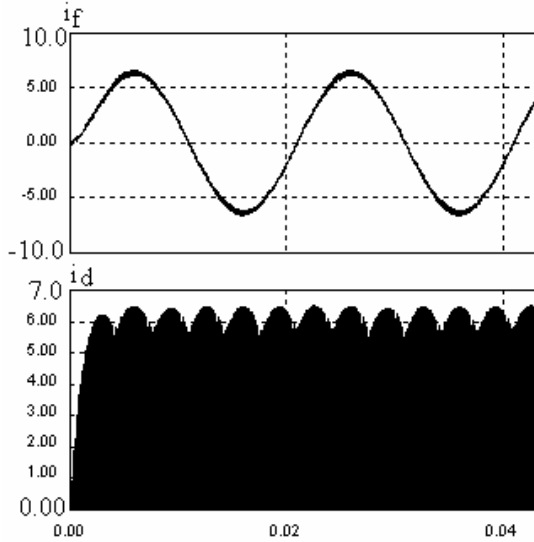

Fig. 8. Simulated diagrams of currents for scheme Fig. 7

Table 4. Experimental results

Meanings	Unit	Experiment	Calcul.
U_{phe}	V	23.6	23.5
I_{phe}	A	4.52	4.48
I_{da}	A	1.52	1.5
φ	^{0}el	16.2	17.43
ΔI_f	A	2.52	2.2

Switching converters with sinus shape input current

For obtaining electromagnetic compatibility of converters with supply grid and compensation of reactive power it is necessary to obtain sinus shape input current of converter. It is possible to apply switching technologies where current pipe is constructed providing tracking of input current to reference one of sinus shape. Every preset deviation up or down of the reference is connected with some switching in circuits of converter.

As example can be examined scheme of single-phase rectifier with input BOOST switch providing such switching that current of the choke is close to the sinus shape half waves (Fig. 9).
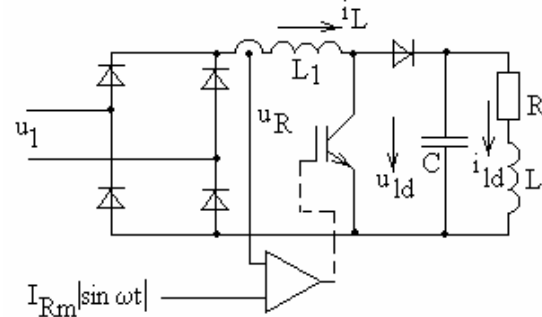

Fig. 9. Scheme of the single-phase rectifier with PWM

For this scheme:
Magnitude of choke's L_1 current

$$I_{Lm} = \frac{2 U_{lda}{}^2}{R U_{1m}} .$$

Duty ratio of switching

$$D = 1 - \frac{U_{Rm}|\sin \omega t|}{U_{lda}} .$$

Frequency of switching

$$f = \frac{[1 - \frac{U_{Rm}|\sin \omega t|}{U_{lda}}] U_{Rm}|\sin \omega t|}{L_1 . \Delta I} .$$

Angle at maximum switching frequency

$$\omega t_m = arctg \frac{U_{lda}}{2 U_{Rm}} .$$

Full deviation of capacitor's voltage

$$\Delta U_C = \frac{I_{lda} L \Delta I}{C U_{Rm}|\sin \omega t|} .$$

Full deviation of load's current

$$\Delta I_{ld} = \frac{\Delta U_C}{8 L f} .$$

In accordance with given expressions in Table 5 a main parameters for $U_{Rm}=U_{1m}$=312 V, f_1=50 Hz, U_{lda}=400 V, ΔI=20 A, L_1=5 mH, R=10 Ω, C=10000μF are presented.

Table 5. Experimental results

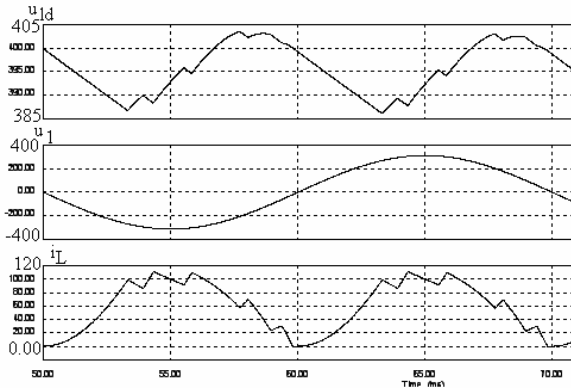| Meanings	Unit	Experim.	Calc.
I_{Lm}	A	105.2	102.5
I_{lda}	A	40.5	40.0
f_{max}	Hz	1000	975
D at f_{max}		0.59	0.58
ΔU_c at $\omega t = 5^0$	V	15.5	14.7
ΔI_{ld} at ΔU_c	A	1.2	1.45

Fig. 10. Simulated diagrams of voltages and currents in the scheme Fig. 9

As last can be presented a scheme of power conditioner shown on Fig.11. Such a scheme without an active load at output can work with input current of sinus shape shifted by +90⁰ or -90⁰. In the first case conditioner is working as regulated capacitor; in the second case – as regulated inductor.
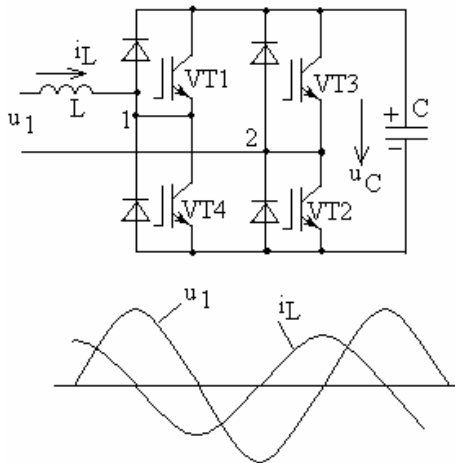

Fig. 11. Scheme of power conditioner and diagrams for it

For this scheme, when operating as capacitor:
Fundamental of input current

$$i_{Lf} = I_{Lm} \sin(\omega t + \pi / 2) .$$

Magnitude of bridge's input and capacitor voltage

$$U_{12m} = U_{cm} = U_{1m} + I_{Lm} \omega L .$$

Fundamental of bridge's input voltage

$$u_{12f} = \left(\frac{t_A}{T} - \frac{t_B}{T} \right) U_{cm} .$$

Full deviation of capacitor voltage

$$\Delta U_C = U_{12m} - \sqrt{U_{12m}^2 - \frac{U_{12m} I_{Lm}}{\omega C}} .$$

Maximal switching frequency

$$f_{max} = \frac{0.5 U_{C0}}{L \Delta I} ;$$

$$U_{C0} = U_{Cm} - 0.5 \Delta U_C .$$

In accordance with given expressions in Table 6 are presented a calculated and experimental meanings of parameters at U_{1m}=312 V, f_1=50 Hz, I_{Lm}=50 A, C=1000 µF, L=1 mH, ΔI=10 A.

Table 6. Experimental results

Meanings	Units	Experim.	Calc.
$U_{12m} = U_{Cm}$	V	371	328
ΔU_C	V	73	92.7
U_{c0}	V	337	281.6
f_{max}	kHz	9.0	14.08

On Fig. 12 are presented simulated diagrams for some meanings presented in the Table.
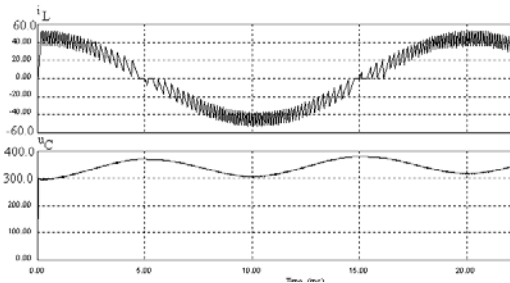

Fig. 12. Simulated diagrams for scheme Fig. 11

Conclusions

1. Application of simulation programs for learning of switching converters is efficient.

2. Coincidence of simulated and theoretical parameters in presented switching schemes is quiet good.

3. Largest non-coincidence can be seen for scheme of power conditioner; it means that needs some improvement of calculation methodology for this kind of converters.

References

1. **Mohan N., Undeland T., Robbins W.** Power Electronics: Converters, Applications and Design. - NY, 1989. - 667 p.

I. Rankis, I. Rodionova. Application of Simulation Packages in Classes of Switching Converters // Electronics and Electrical Engineering. – Kaunas: Technologija, 2006. – No. 4(68). – P. 23-28.

Tere are presented results of computer simulation of power electronic circuits applying programme package PSIM. Such a simulation is foreseen for teaching of students on subject of learning of switching converters, i.e. converters realized on base of powerful transistors switched with free preset frequency and different algorithms of control. In the first part a DC/DC converters are examined and simulation results compared with ones calculated by formulas describing processes. It is shown that coincidence is very good. The next part is devoted to examining of switching converters with sinus shape output current which are basic for sinus shape PWM technologies. Single phase and three phase schemes are examined and results of simulation are satisfying. As the third part are presented schemes for obtaining a sinus shape of input current of different sorts of line-frequency converters. Presented equations can be applied for teaching of students on subject of power electronics, but application of programming packages allow to virtualized learning process. Il. 12, bibl. 1 (in English; summaries in English, Russian and Lithuanian).

И. Ранькис, И. Родионова. Применение моделирующих программ для изучения коммутируемых преобразователей // Электроника и электротехника. – Каунас: Технология, 2006. – № 4(68). – С. 23-28.

Представлены результаты исследования компьютерным моделированием с использованием типовой программы ПСИМ цепей коммутируемых преобразователей энергии. Такое моделирование используется для обучения студентов предмету о б одной из частей силовых преобразователей – коммутируемых, т.е., переключаемых со свободно устанавливаемой частотой и алгоритмом переключений. В первой части исследованы преобразователи постоянного тока в постоянный и результаты моделирования сравниваются с расчетными по упрощенным выражениям, описывающими процессы. Совпадение хорошее. Во второй части рассмотрены преобразователи с синусоидальным током на выходе, которые являются основой для современных синусоидальных ШИМ преобразователей. В третьей части рассмотрены сетевые преобразователи с синусоидальным током на входе. Предложенные выражения могут быть использованы для изучения студентами процессов, а моделирующие программы позволяют оживить материал. Ил. 12, библ. 1 (на английском языке; рефераты на английском, русском и литовском яз.).

I. Rankis, I. Rodionova. Modeliavimo programų taikymas komutuojamiems keitikliams tirti // Elektronika ir elektrotechnika.- Kaunas: Technologija, 2006. – Nr. 4(68). – P. 23-28.

Pateikiami komutuojamų energijos keitiklių grandinių kompiuterinio modeliavimo rezultatai, gauti panaudojus tipinį PSIM programų paketą. Toks modeliavimas naudojamas mokymo procese, supažindinant studentus su komutuojamaisiais keitikliais, t.y. tokiais keitikliais, kurie perjungiami su laisvai pasirenkamu dažniu ir perjungimo algoritmu. Ištirti pastoviosios srovės keitikliai ir gauti modeliavimo rezultatai sulyginti su skaičiavimais, atliktais pagal supaprastintas išraiškas, aprašančias procesus.

Išanalizuoti keitikliai, kurių srovė išėjime yra sinusinė ir kurie sudaro šiuolaikinių PWM keitiklių pagrindą. Išnagrinėti tinklo keitikliai su sinusine srove įėjime. Pasiūlytomis išraiškomis studentai gali naudotis mokymo procese, o modeliavimo programos leidžia atnaujinti turimą medžiagą. Il. 12, bibl. 1 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).