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ANALYSIS AND SIMULATION OF THE SWITCHING PULSE CONVERTORS

The algorithm for transient analysis of the switching power supplies, based on energy conservation principle is presented. At each time step the energy stored in the circuit and energy flow between circuit elements are computed. This algorithm is very rapid and can be implemented even on small personal computers. The developed computer program for the analysis of switching pulse convertors allows to investigate transient response of the circuit for various circuit parameters. It is also possible to investigate in detail various secondary effects.

1. INTRODUCTION

The efficiency of the switching DC-DC converter structures for the power conversions can be as high as 90 percent. Those type of structures play dominant role in the power supplies for electronic equipment. It is not possible to fully integrated those structures, and the hybrid form is the only possible one. Design and analysis of the DC-DC convertors is very complex. Especially difficult is to predict the long term transient behavior as the result of the variation of pulse duty ratio or variation of the load changes. The only practical way of the analysis, is to use the computer simulation.

The algorithm presented in this paper is an extension of the algorithm presented in [3] which was based on the charge conservation principle. The presented version is based on the energy conservation principle and therefore inductive elements can be also included. This algorithm is suitable for complex investigation of transient responses of DC-DC convertors. It also allows to include such secondary effects as series resistances of the switches, loses in both inductances and capacitances.

2. PRINCIPLE OF ALGORITHM

Algorithm bases on the energy conservation principle in the analyzed circuit. Energy stored in inductive elements is directly related to the current flowing through the inductance. This current is given by the relation:

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$$I(t) = I_o + 1/L \int_0^t U(t)\, dt \qquad (1)$$

The integral form of the above equation is very convenient for the numerical analysis in the time domain. At every time step the energy stored in the inductive element is corrected by the energy increment which is proportional to the time step duration and to the instantaneous voltage drop on this element. Using linear approximation of equation (1) the current in the n-th time step can be expressed as follow:

$$I_n = I_{n-1} + U_n \cdot \Delta t/L \qquad (2)$$

In order to improve accuracy and to increase the time step the above first order method of integration can be of course replaced by higher order method.

Energy stored in the capacitive element is directly related to the voltage drop between plates of capacitor. The voltage on the capacitance varies with time according to the relation:

$$U(t) = U_o + 1/C \int_0^t I(t)\, dt \qquad (3)$$

With the first order approximation the voltage for the n-th time step is given by equation:

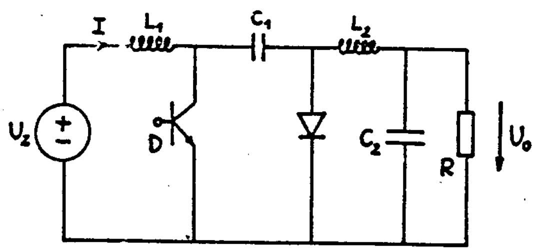
$$U_n = U_{n-1} + I_n \cdot \Delta t/C \qquad (4)$$

The accuracy of computation increase with decrease of the time step Δt. This leads however to the increase of the number of the time steps and to the increase of the computing time. The switching power supply are designed usually in such way that switching time is much smaller than the time constants in the circuits. The only exception is the resonance type switching power supply, where the switching time corresponds to the time constant of the circuits. Therefore for most of the switching power supplies the time step can be equal to the switching time. Only in resonance type convertors the time step should be smaller. Also much smaller time step has to be chosen in case of detail analysis of secondary effects during switching.

Other part of the algorithm bases on the current balance of inductances and on the voltage balances on the capacitances. The currents flowing into capacitances are computed as an unbalanced inductive currents. The voltage drop on the inductances are computed as the voltage difference between fixed voltage on the capacitances. This simple approach is possible only for the switching power supplies. In this class of the circuits the computation process is precisely defined. The secondary effects as: the series resistances of inductances, voltage drops of switches, leakage currents of capacitances, series and parallel resistances of switches are also included. Those secondary effects are computed as the corrections at each time step.

3. APPLICATION OF THE ALGORITHM

The computer program for the analysis of all class two-state switching DC-DC convertors [1] has been developed. It allows to investigate the transient responses of switching power supplies caused by the variation of the pulse duty ratio or by the time depended variation of the load. Also various secondary effects can be precisely tested. Figure 2 shows the results of the stationary analysis of CZUK type converter, which circuit diagram with value of elements is given in figure 1. The ripple of input current and the ripple of output voltage are shown in figure 2. One can observe very small current and the voltage variations.



U_z = 10 V
$L_1 = L_2$ = 200 µH
$R_{L1} = R_{L2}$ = 0.1 Ω
C_1 = 1000 µF
C_2 = 470 µF
$R_{C1} = R_{C2}$ = 10 mΩ
R = 5 Ω
f_x = 20 kHz
D = 0.5 (duty ratio)

Fig. 1. Circuit diagram of CZUK type converter.

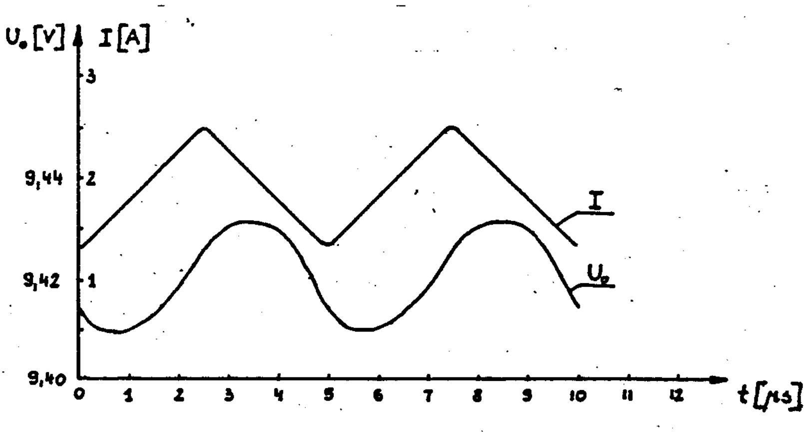


Fig. 2. Input current and output voltage waveforms of the CZUK type converter shown in figure 1.

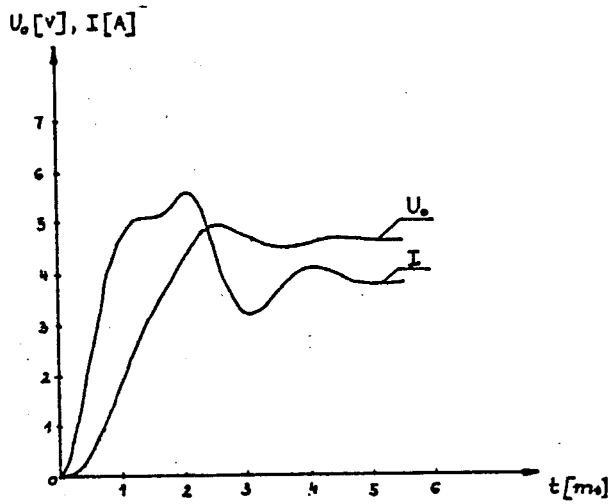
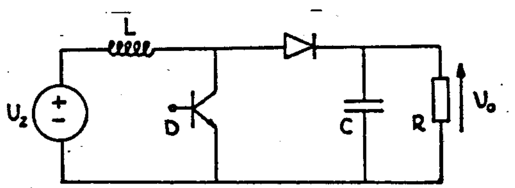


Fig. 5. Transient response of the circuit from figure 3 for the linearly increased pulse duty ratio from 0 to 0.5 in 2 ms.

Other example is the BOOST type converter shown in figure 6. In this case the effect of the rapid variation in the load is analyzed, and results are shown in figure 7.



U_Z = 10 V
L = 100 μH
R_L = 0.1 Ω
C = 100 μF
R_C = 10 mΩ
f_x = 33.333 kHz
D = 0.5

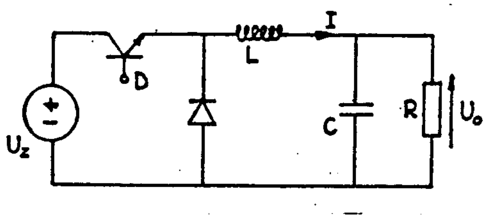
Fig. 6. Circuit diagram of BOOST type converter.

The program allows to observe on the screen the transient responses of voltages and currents. It is possible to change the circuit parameters even during analysis. This program is the powerful tool for the analysis and design of the power switching supplies. Its importance is underlined by the fact that those circuits are to complex for analytical approach.

4. CONCLUSION

With the approximations given by relation (2) and (4) the computation algorithm is very fast because at each time step the only very simple arithmetic operations are proceeded. Algorithm takes also

The circuit of the BUCK type converter is shown in figure 3. The transient responses of this circuit are shown in figure 4 and 5. In figure 4 the duty ratio was changed suddenly from 0 to 0.5 and as result large magnitudes of the transient current and voltage occurs. When duty ratio increased linearly from 0 to 0.5, in the time of 2 ms (figure 5) magnitudes of transient currents and voltages are much smaller. Moreover the steady state in late case is reached faster. It can be seen that unproper control of switching power supply may lead to abnormal increase of currents or voltages, and it may damage the circuits elements.



U_z = 10 V
L = 100 µH
R_L = 0.1 Ω
C = 1000 µF
R_C = 10 mΩ
R = 1.2 Ω
f_x = 25 KHz
D = 0.5

Fig. 3. Circuit diagram of BUCK type converter.

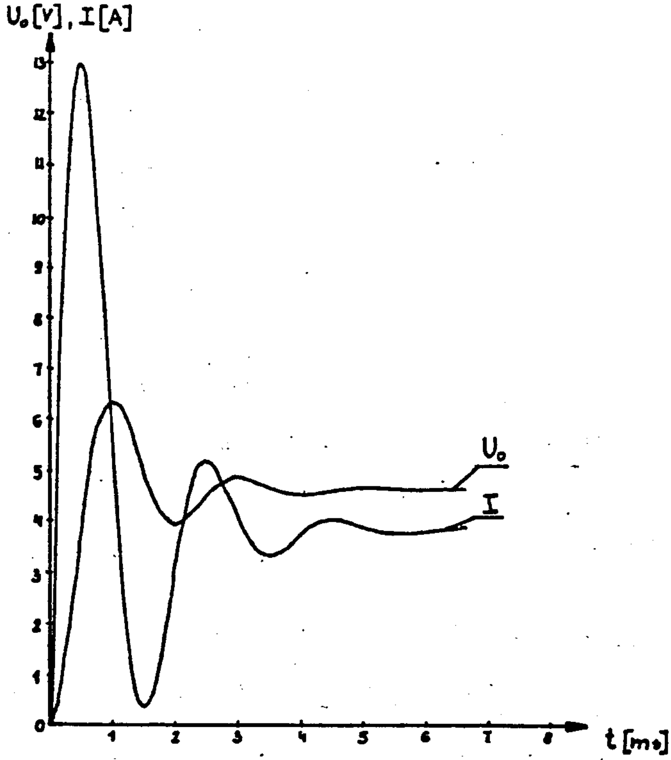


Fig. 4. Transient response of the circuit from figure 3 for the rapid variation pulse duty ratio from 0 to 0.5.

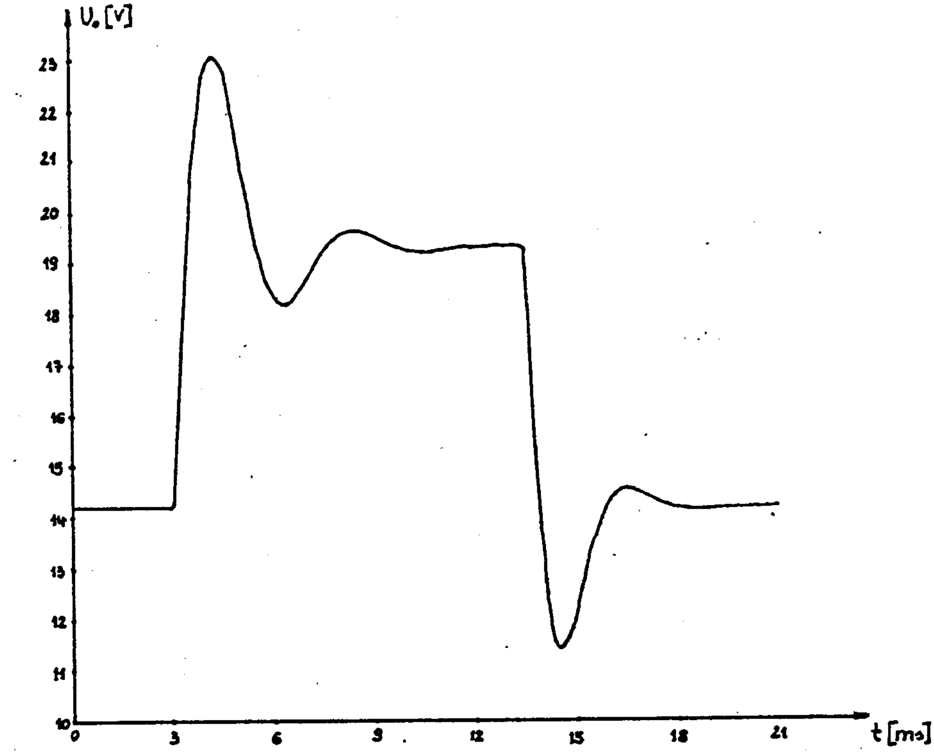


Fig. 7. Output voltage waveform of the circuit from figure 6, as the result of the rapid load variations: at 3 ms from R = 1 Ω to R = 10 Ω, and at 13.5 ms from r = 10 Ω to R = 1 Ω.

advantage of the special properties of circuit, which belong to the class of the two-state switching power supplies. Computation is very rapid and memory requirements are negligible. Therefore it is possible to use this algorithm even on small "home type" personal computers.

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