# Investigation of a Method for Power Control of a DC/DC Transistor Resonant Converter

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*Abstract* – **A deep power control method of a transistor DC/DC converter has been suggested. The method is based on varying the duration of the inverter transistor turn-on time operated above the resonant frequency. A family of the converter load characteristics has been drawn. The control system block-diagram and converter main steady-state equations, which allow fast engineering design, are proposed.**

**The main theoretical results are proved by computer simulation using OrCAD PSpice.**

*Keywords* – **resonant DC/DC converter, control method**

## I. INTRODUCTION

The transistor DC/DC converter operated above the resonant frequency becomes more favorable as the feed source for the different electrotechnological purposes, by reason of unique energetic factors and high reliability of operation.

The large number of publications in this area is a good evidence of increased interests- [1], [2], [4] etc.

A method for output power control of transistor resonant inverters, which has not been thoroughly studied, based on varying the duration of the transistor turn-on time, have been reported in the literature [3] and [4]. This method is completely applicable by DC/DC converters.

In this paper an output power approach of the transistor resonant DC/DC converter operated above resonant frequency by varying the duration of the transistors turn-on time is presented. A family of the inverter load characteristics during the supply of the strongly variables loads has been drawn. The block-diagram of one version of a control system is proposed.

The converter main steady-state equations are presented, which allow fast engineering design.

## II ANALYSIS AND LOAD CHARACTERISTICS OF THE DC/DC CONVERTER

Fig.1 shows proposed DC/DC converter and a control system block-diagram.

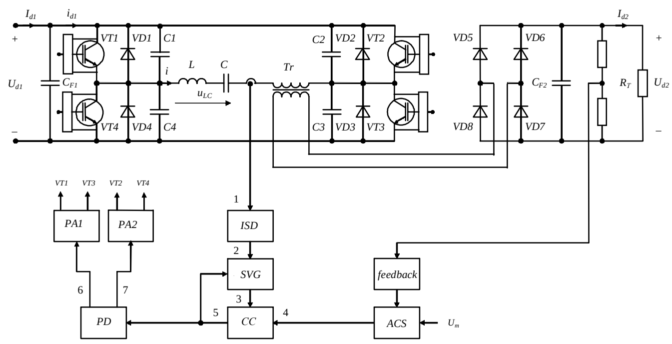


Fig.1. DC/DC converter and a control system block-diagram

The analysis and design of such converter are presented in [1] and [2]. The analysis is made under the following assumptions: the matching transformer is ideal; transformer turn ratio is one, the converter elements are ideal; the effect of snubber capacitors and the ripples of input and output voltages are neglected.

The results from the analysis are shown in table 1, where the following common symbols are used:

- $\omega_0 = 1/\sqrt{LC}$ - resonant frequency; $Z_0 = \sqrt{L/C}$ - intrinsic impedance;
- $\omega$ - switching frequency;
- $u_{LC}$ – voltage across resonant link $L$-$C$ for each stage of the converter operation Eq. (3);
- $i(0)$ , $u_C(0)$ – initial values of the resonant link current and voltage across series capacitor for each stage of the converter operation - Eqs. (4) and (5);
- $\theta_{VT} = \omega_0 \cdot t_{VT}$ - transistors conduction angle;
- $\theta_{VD} = \omega_0 \cdot t_{VD}$ - diodes conduction angle.

For unifying purposes all units are presented as relative ones: the voltages to the supply voltage $U_{d1}$; the currents to the current $I = U_{d1}/Z_0$; the input power to the power $P = U_{d1}^2/Z_0$ .

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TABLE I

RESULTS FROM ANALYSIS

| Quantity | Expression | |
|---|---|---|
| $i(\omega_0 t)$ | $\dfrac{u_{LC} - u_C(0)}{Z_0} \cdot \sin\omega_0 t + i(0) \cdot \cos\omega_0 t$ | (1) |
| $u_C(\omega_0 t)$ | $u_{LC} - [u_{LC} - u_C(0)] \cdot \cos\omega_0 t + i(0) \cdot Z_0 \cdot \sin\omega_0 t$ | (2) |
| $u_{LC}$ | 1. $U_{d1} + U_{d2}$  3. $-U_{d1} - U_{d2}$ <br> 2. $U_{d1} - U_{d2}$  4. $-U_{d1} + U_{d2}$ | (3) |
| $i(0)$ | 1. $-I_0$  3. $I_0$ <br> 2. 0  4. 0 | (4) |
| $u_C(0)$ | 1. $-U_{C0}$  3. $U_{C0}$ <br> 2. $-U_{Cm}$  4. $U_{Cm}$ | (5) |
| $I'_0$ | $\dfrac{I_0}{U_{d1}/Z_0} = \dfrac{(1-U'_{d2}) \cdot \sin\theta_{VT}}{U'_{d2} + \cos\theta_{VT}}$ | (6) |
| $U'_{C0}$ | $\dfrac{U_{C0}}{U_{d1}} = \dfrac{U'_{d2} \cdot (1-U'_{d2}) \cdot (1-\cos\theta_{VT})}{U'_{d2} + \cos\theta_{VT}}$ | (7) |
| $U'_{Cm}$ | $\dfrac{U_{Cm}}{U_{d1}} = \dfrac{(1-U'_{d2}) \cdot (1-\cos\theta_{VT})}{U'_{d2} + \cos\theta_{VT}}$ | (8) |
| $\theta_{VT}$ | $\dfrac{\pi}{\omega/\omega_0} - \theta_{VD}$ | (9) |
| $\theta_{VD}$ | $arctg\,\dfrac{(1-U'^2_{d2}) \cdot \sin\theta_{VT}}{2U'_{d2} + (1+U'^2_{d2}) \cdot \cos\theta_{VT}}$ | (10) |
| $I'_{d2}$ | $\dfrac{2 \cdot (1-U'_{d2}) \cdot (1-\cos\theta_{VT})}{(U'_{d2} + \cos\theta_{VT}) \cdot (\theta_{VT} + \theta_{VD})}$ | (11) |
| $I'_{d1} = P'_d$ | $\dfrac{2U'_{d2} \cdot (1-U'_{d2}) \cdot (1-\cos\theta_{VT})}{(U'_{d2} + \cos\theta_{VT}) \cdot (\theta_{VT} + \theta_{VD})}$ | (12) |
| $I'_{VT_{AV}}$ | $\dfrac{(1-U'^2_{d2}) \cdot (1-\cos\theta_{VT})}{2 \cdot (U'_{d2} + \cos\theta_{VT}) \cdot (\theta_{VT} + \theta_{VD})}$ | (13) |
| $I'_{VD_{AV}}$ | $\dfrac{(1-U'_{d2})^2 \cdot (1-\cos\theta_{VT})}{2 \cdot (U'_{d2} + \cos\theta_{VT}) \cdot (\theta_{VT} + \theta_{VD})}$ | (14) |
| $I'_m$ | $\dfrac{1-U'^2_{d2}}{U'_{d2} + \cos\theta_{VT}}$ | (15) |

When a parameter for converter output power control is angle, respectively the transistors turn-on time, the latter in relative units should be presented in the following way:

$$\theta'_{VT} = \frac{\theta_{VT}}{\pi} = \frac{t_{VT}}{T_0/2} = t'_{VT} \qquad (16)$$

Solving equations from Table 1 can be drawn an inverter family of load characteristics. Those are the relationships of the converter main variables as a function of the output current $I'_{d2}$ and angle, respectively the transistors turn-on time $\theta'_{VT}$ in relative units.

The following relations can be of great interest: the converter output voltage $U'_{d2}(I'_{d2}, \theta'_{VT})$, the input power and the input current $I'_{d1} = P'_d(I'_{d2}, \theta'_{VT})$, the transistors average current $I'_{VT_{AV}}(I'_{d2}, \theta'_{VT})$ and the freewheeling diodes average current $I'_{VD_{AV}}(I'_{d2}, \theta'_{VT})$, the peak capacitor voltage $U'_{Cm}(I'_{d2}, \theta'_{VT})$ and the switching frequency ratio $\nu(I'_{d2}, \theta'_{VT})$, where $\nu = \omega/\omega_0$.

Fig. 2 ÷ 7 show corresponding graphs by $\theta'_{VT}$ = 0,80; 0,60; 0,45 and 0,30.

The description of the DC/DC converter load characteristics is identical to these that are referred only to the resonant inverter [3].

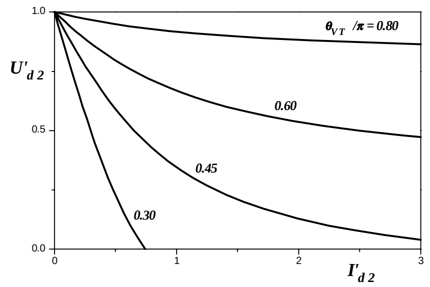


Fig.2. Normalized output characteristics of the converter

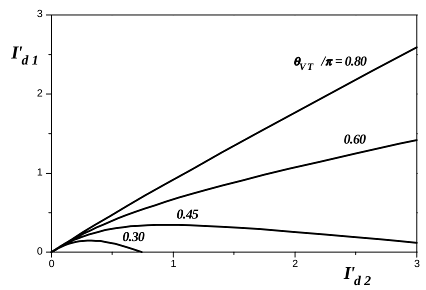


Fig.3. Normalized input current $I'_{d1}$ (input power) as a function of output current $I'_{d2}$

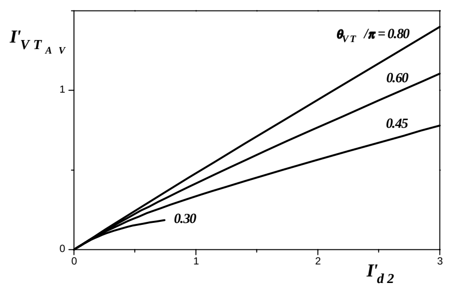


Fig.4. Normalized transistors average current $I'_{VT_{AV}}$ versus normalized output current $I'_{d2}$ for different values of normalized transistors turn-on time $\theta'_{VT}$

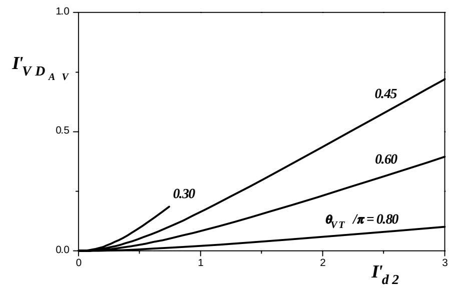


Fig.5. Normalized antiparallel diodes average current $I'_{VD_{AV}}$ against normalized output current $I'_{d2}$ for different values of normalized transistors turn-on time $\theta'_{VT}$

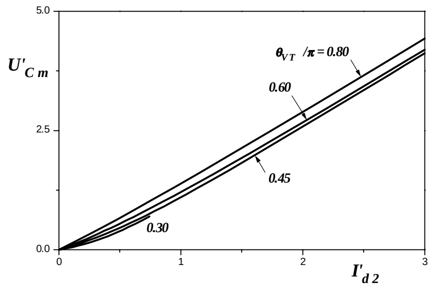


Fig.6. Normalized peak capacitor voltage $U'_{Cm}$ as a function of normalized output current $I'_{d2}$ for different values of normalized transistors turn-on time $\theta'_{VT}$

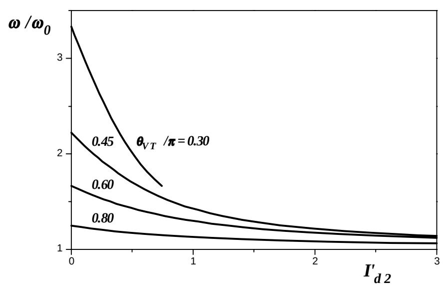


Fig.7. Switching frequency ratio as a function of normalized output current $I'_{d2}$ for various normalized transistors turn-on time $\theta'_{VT}$

## III. CONTROL SYSTEM OF THE INVERTER

Fig.1 shows proposed control system block-diagram with the considered DC/DC converter. The operation of the control system (CS) is synchronized with the resonant link current **i**.

The input synchronizing device (ISD) shapes pulses, which give information when the resonant current crossing zero. These pulses start the sawtooth voltage generator (SVG). The voltage increasing time is equal to the transistors turn-on time.

SVG output voltage is sent to the one input of the comparison circuit (CC). The automatic control system (ACS) output voltage is delivered to another CC input.

The shaped pulses of the CC output zeroing SVG and are fed to the pulse distributor (PD). Pulse distributor forms 2 channels of control pulses, dephased at $180^0$. The pulse amplifiers (PA1 and PA2) provide the required power, amplitudes and galvanic separation of the control signals.

ACS provides the necessary change of the CC control function, aiming to stabilize or regulate the inverter parameters according to a certain rule under the feedback.

Fig.8 shows the waveforms in significant points, which explain the system operation.

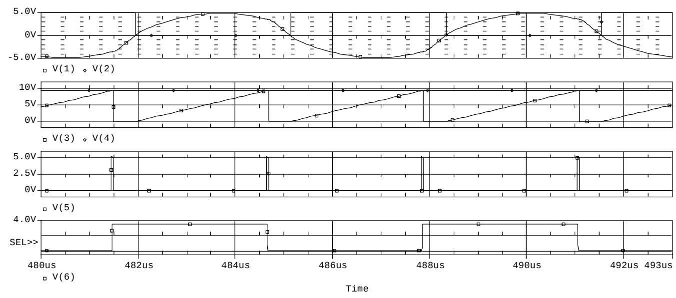


Fig.8. Control system waveforms

## IV. DESIGN AND COMPUTER SYMULATION

Based on the analysis we have made and the load characteristics by given input and output voltages $U_{d1}$ and $U_{d2}$, switching frequency $f$ and output power $P$, the following design method can recommend.

1. The normalized output voltage is found from - $U'_{d2} = U_{d2}/U_{d1}$.

2. The normalized transistors turn-on time $\theta'_{VT}$ value is chosen, which determined the type of the output characteristics depending on industrial process requirements. In this way the operating points on the load characteristics at the rated load are determined. All the base converter quantities in relative units become known.

3. The value of $Z_0$ can be expressed as:

$$Z_0 = \frac{U_{d1}^2}{P} \cdot P'_d \tag{17}$$

4. The resonant frequency $\omega_0$ can be calculated as:

$$\omega_0 = (2 \cdot \pi \cdot f)/\nu \tag{18}$$

5. The values of $L$ and $C$ from $Z_0$ and $\omega_0$ can be evaluated as:

$$L = Z_0/\omega_0 \tag{19}$$

$$C = 1/(Z_0 \cdot \omega_0) \tag{20}$$

6. The base quantity values in real units, necessary to choose the converter elements are calculated.

The computer simulation of the DC/DC converter without matching transformer is given by the following conditions: power supply $U_{d1}$=300V; output voltage $U_{d2}$=260V; switching frequency $f$=150kHz; output power $P$=3kW; and resonant link elements $L$= 33.975μH and $C$= 44.937nF. The value of the $\theta_{VT}$=0,75π rad is determined.

Fig.9 sows simulation results, which are compared with theoretical results in table2. A good coincidence between theoretical and simulation results can be seen.

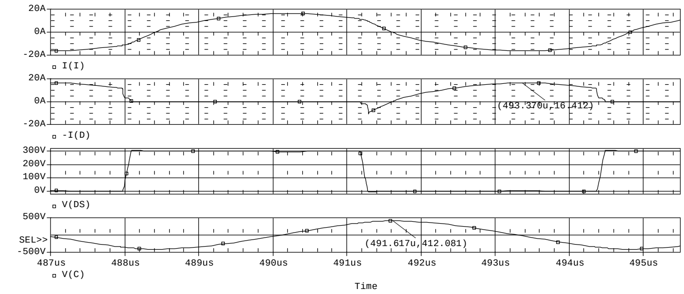


Fig.9. Simulation results

TABLE II
COMPARISON BETWEEN THEORETICAL AND SIMULATION RESULTS

| | $t_{VT}$ | $t_{VD}$ | $I_{d1}$ | $I_{d2}$ | $I_m$ | $U_{Cm}$ |
|---|---|---|---|---|---|---|
| | μs | μs | A | A | A | V |
| Evaluation | 2.9113 | 0.4220 | 10.00 | 11.538 | 17.019 | 427.95 |
| From PSpice | 2.8736 | 0.4592 | 10.06 | 11.550 | 16.412 | 412.08 |

## V. CONCLUSIONS

A method has been suggested for a deep regulation of the DC/DC converter operated above the resonant frequency by varying the duration of the transistor turn-on time. A version of a control system is shown. Converter analysis known from literature has been used and its load characteristics have been built. They allow to evaluate the behavior of the considered converter when the load is changed strongly during the operation process. The main steady-state equations are presented, which allow fast engineering design. A very good coincidence has been obtained between theoretical results and those from computer simulation.

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