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NUMERICAL SIMULATION OF DC-DC BOOST CONVERTER IN CONTINUOUS MODE

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Abstract – For DC-DC power converters in continuous mode of operation, three models where derivate, based on various degrees of approximation of the fundamental equation. In order to observe the errors of each model, a numerical simulation using these (three) analytical models was accomplished. The "etalon" with which these models are compared is based on PSpice simulation software.

Key words: numerical simulation, DC-DC boost converter, continuous mode

1. INTRODUCTION

DC-DC power converters are a category of variant nonlinear discrete systems. To model such a converter in an exact manner is a difficult task and the result is a set of intricate equations, difficult to apply.

Generally, they are two kinds of models:

- Models employing a discrete description, which take into account the discrete nature of the DC-DC switching converters;
- Models describing the converter behavior in terms of linear continuous models.

The second category, more simple and easier to use, consider a small amplitude of perturbations in input (supply) voltage and load resistor. The designer can easily apply the classical linear feedback theory for stability and controller design.

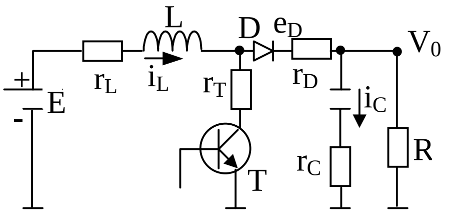

Figure 1.1. Boost DC-DC converter circuit diagram

The schematic circuit of a boost converter is given in figure 1.1.

2. DISCRETE NONLINEAR RECURRENCE

For the inductor current $I_L(t)$, we have (figure 2.1):

$$i_M = i_m + \frac{E}{L} \cdot t_{ON} = i_m + \frac{E}{L} \cdot \mu \cdot T_S \qquad (1)$$

$$i_f = i_M + \frac{E - V_0}{L} \cdot t_{OFF} = i_M + \frac{E - V_0}{L} \cdot (1 - \mu) \cdot T_S \qquad (2)$$

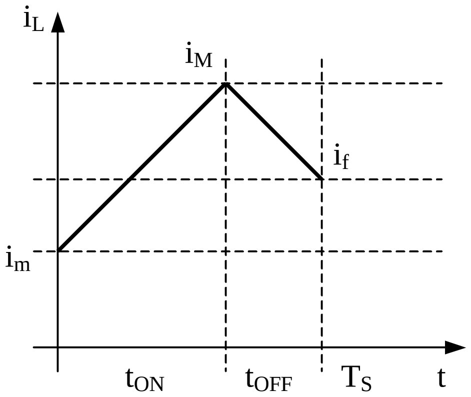

Figure 2.1. Inductor current wave shape

The parasitic elements r_L, r_C, etc. where neglected.

In the steady-state $i_f = i_M$ so that

$$\frac{E}{L} \cdot \mu = \frac{V_0 - E}{L}(1 - \mu).$$

After simple manipulation results a well-known equation:

$$V_0 = \frac{1}{1 - \mu} \cdot E \ . \qquad (3)$$

For the output voltage, we have:

$$\begin{cases} v_{0m} = V_{0M} \cdot e^{-\mu T_S / RC} \\ v_{0M} = V_{0M} + \displaystyle\int_0^{(1-\mu)T_S} \left(-\frac{1}{RC} \cdot v_0(t) + \frac{1}{C} \cdot i_L(t) \right) dt \end{cases} \qquad (4)$$

3. CONTINUOUS "NONLINEAR" EQUATIONS

The set of **nonlinear continuous equations** are based on the slope of inductor current or output voltage over a period (T_S) using (2) and (4):

$$\begin{cases} \dfrac{di_L(t)}{dt} = \dfrac{i_f - i_m}{T_S} - \left[\dfrac{E}{L} - (1 - \mu_1) V_0(t) \right] \\ \dfrac{dV_0(t)}{dt} \cong -\dfrac{V_0}{RC} + \dfrac{i_f + i_m}{2} \cdot (1 - \mu_1) \end{cases} \qquad (5)$$

For instance, if initially $(\mu = \mu_0)$ for which, in steady-state:

$$i_{Lss} = \frac{E}{R(1 - \mu_0^2)}; \ V_{0ss} = \frac{E}{(1 - \mu_0)} \qquad (6)$$

by a step $\Delta\mu = \mu_1 - \mu_0$, the evolution of state variables, over a switching period, is:

$$\begin{cases} \bar{i}_L(t) \cong i_L(0) + \dfrac{1}{L}\left[E - (1 - \mu_1) \cdot V_0(0)\right] \cdot t \\ \bar{v}_0(t) \cong V_0(0) + \left[\dfrac{i_L(0) + i_L(t)}{2} \cdot \dfrac{(1 - \mu_1)}{C} - \dfrac{V_0(0)}{RC} \right] \cdot t \end{cases} \qquad (7)$$

For the first step, $i_L(0) = i_{Lss}$; $v_0(0) = v_{0ss}$.

4. LINEARIZED TRANSFER FUNCTIONS

Using the state-space averaging method, the linearized transfer function for a change of the duty ratio $\Delta\mu = \mu_1 - \mu_0$ is presented in figure 4.1, where

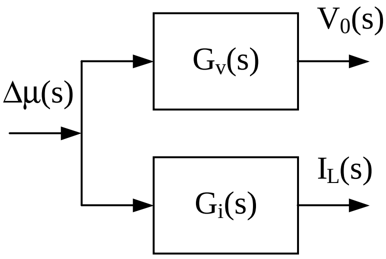

Figure 4.1. Linear model of the switching boost converter

$$G_V(s) = k_v \cdot \frac{1 - \frac{s}{z_V}}{\frac{s^2}{\omega_0^2} + \frac{s}{Q\omega_0} + 1} \qquad (8)$$

$$G_i(s) = k_i \cdot \frac{1 + \frac{s}{z_i}}{\frac{s^2}{\omega_0^2} + \frac{s}{Q\omega_0} + 1} \qquad (9)$$

and

$$\begin{cases} k_v = \dfrac{E}{(1-\mu_0)^2}; & k_i = \dfrac{2E}{(1-\mu_0)^3} \\ z_v = \dfrac{(1-\mu_0)^2 \cdot R}{L}; & z_i = \dfrac{2}{RC} \\ \omega_0 = \dfrac{(1-\mu_0)}{\sqrt{LC}}; & Q = (1-\mu_0) \cdot R \cdot \sqrt{\dfrac{C}{L}} = \omega_0 RC \end{cases} \qquad (10)$$

5. SIMULATIONS

The particular data of a fictitious DC-DC boost converter are:

- Unregulated DC power supply: E = 24V;
- Inductor value: L = 3.41mH;
- Capacitor value: C = 500μF;
- Switching frequency: f_s=20kHz ($T_S=1/f_S$);
- Load resistor: R = 100Ω (which ensures a continuous mode of operation);
- Parasitic elements: inductor resistance: r_L = 0.46Ω, capacitor resistance: r_C=0.2Ω, transistor resistance in ON state: r_T =0.25Ω, diode direct voltage drop e=0.6V.

5.a.. Using the continuous nonlinear equations (equations (7)), with initial value of the duty ratio factor μ_0=0.5, the particular equations for $\mu \to \mu_0 + 0.1$ are:

$$i_L(\tau) = i_L(\tau - T_S) + 0.0000007(24 - 0.4V_0(\tau - T_S)) \cdot \tau \text{ and}$$

$$V_0(\tau) = V_0(\tau - T_S) + 0.0000077\big((i_l(\tau) + i_L(\tau - T_S)) - 0.05V_0(\tau - T_S)\big) \cdot \tau \qquad (7^*)$$

In numerical example, the computing step was $\Delta t = 5.10^{-5}$sec.

The simulation program consists of three experiences:

$\mu \rightarrow \mu_0 + 0.1$; $\mu \rightarrow \mu_0 + 0.2$; $\mu \rightarrow \mu_0 + 0.3$

The results of simulations are given in figure 5.1.

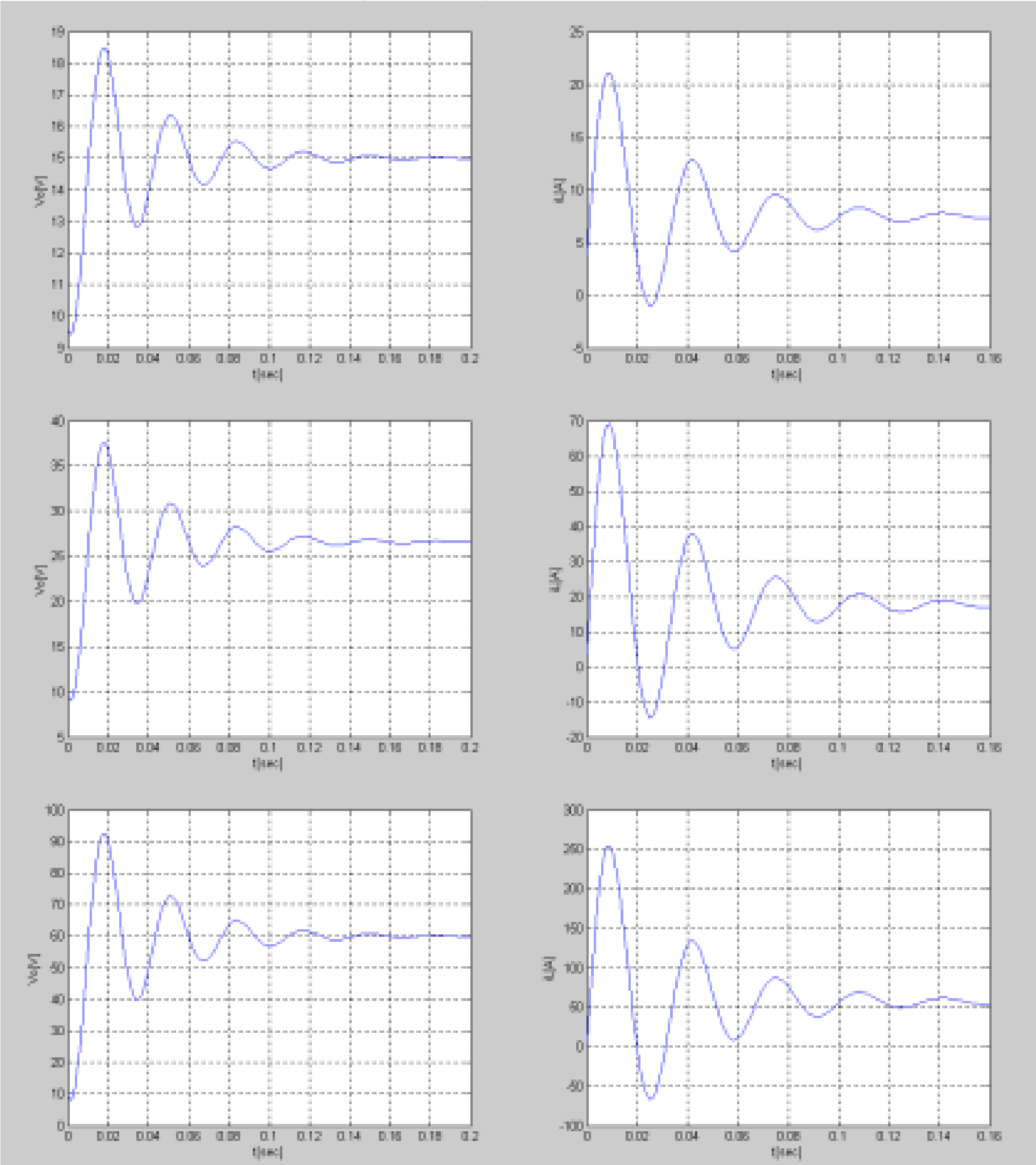

Figure 5.1. Simulation results using continuous "nonlinear" equations

5.b. Using the linearized transfer functions (equations (8) and (9)), the results of simulation for steps in μ (0.1 and 0.2), are presented in figure 5.2.

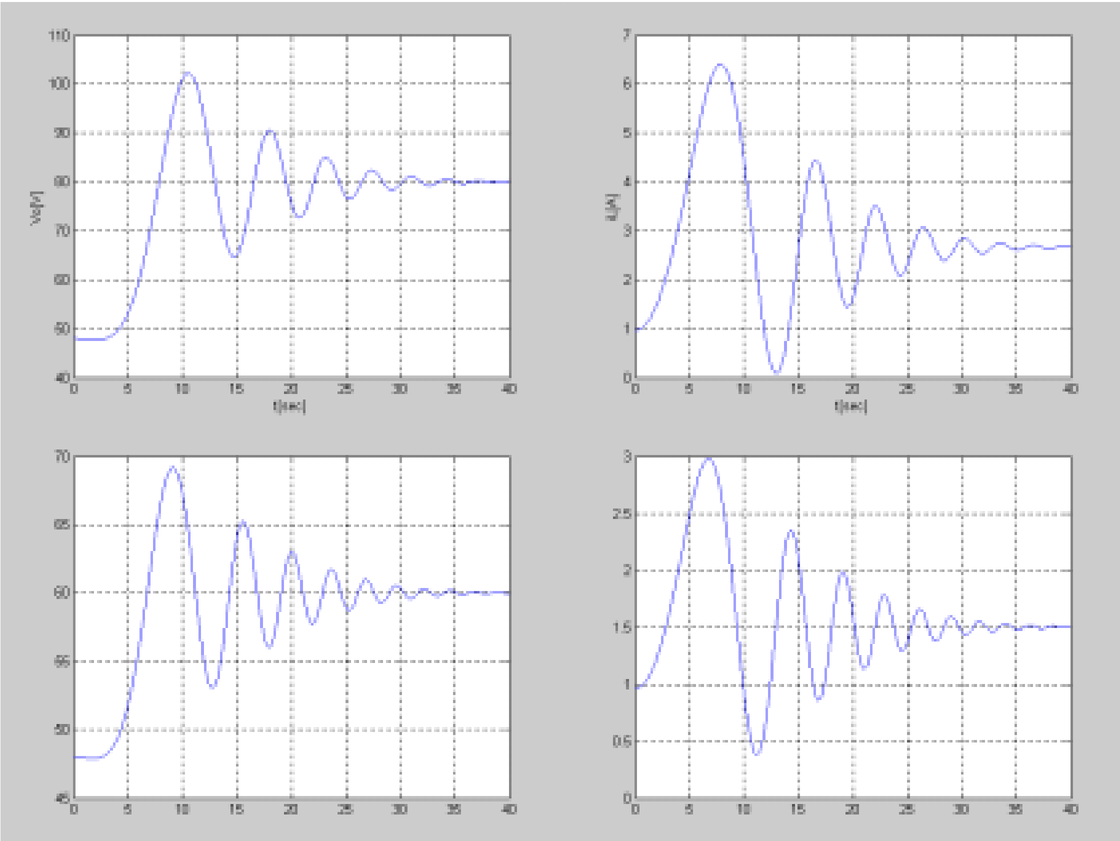

Figure 5.2. Simulation results using linearized transfer functions

It is important to note that the **scale factors** are quite different in each simulation experiment.

5.c. Using the PSpice simulation software, with a power supply $E^{*}=E/3=8V$, the simulation results are given in figure 5.3.a and b with:

a: μ→0.4 – 0.7; b: μ→0.7 – 0.4;

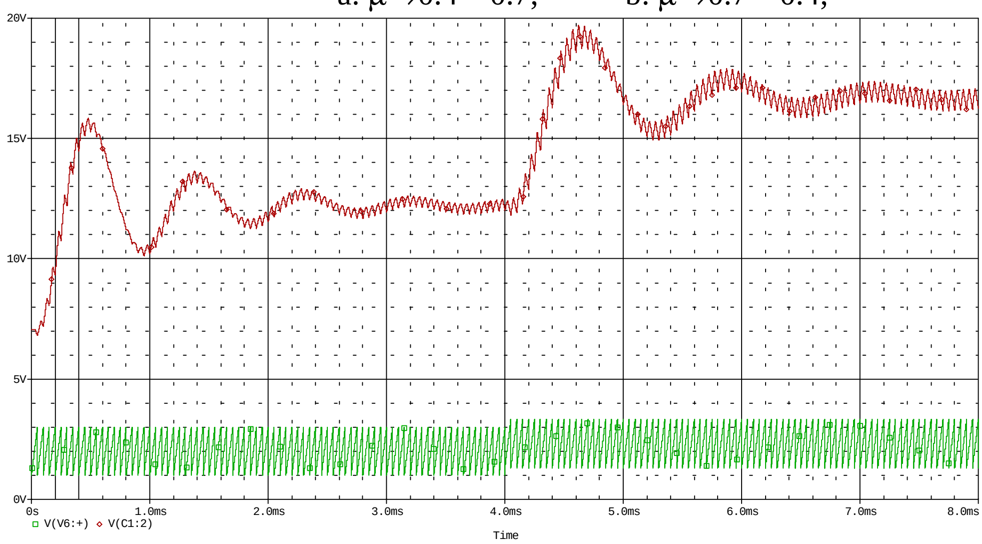

Figure 5.3.a.

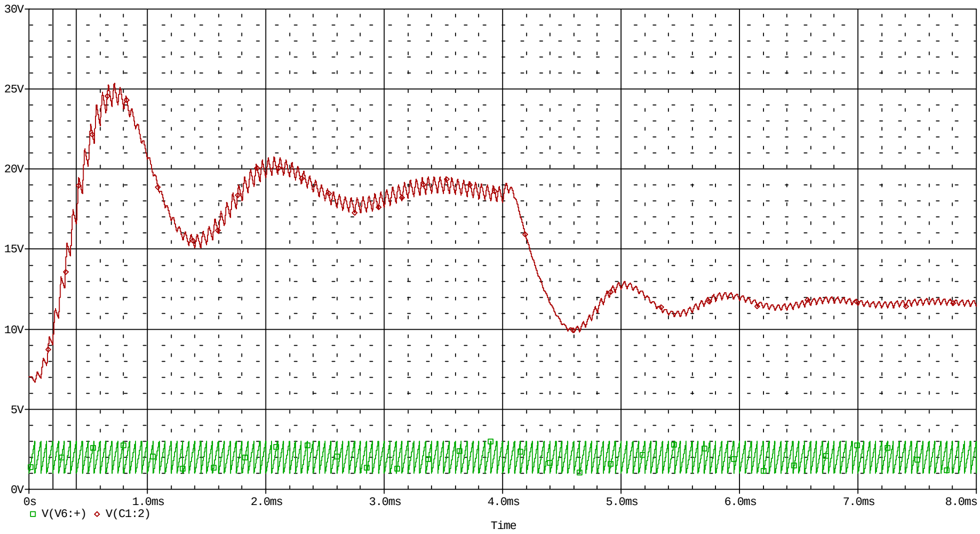

Figure 5.3.b. Simulation using PSpice

6. CONCLUSIONS

The results of simulation with continuous "nonlinear" equations and also with linearized transfer functions show a poor damping of the transients. This can be explained with the lack of the parasitic elements r_L = 0.46Ω, r_C=0.2Ω, r_T =0.25Ω, e=0.6V.

The difference between the result with linearized transfer functions and the results of the PSpice Simulation is greater if the "distance" of the new value of the duty ratio factor compared to μ_0=0.5 is "longer". This is expected because a linearized model is valid only around a certain point of operation.

LITERATURE

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