FAST CURRENT CONTROL FOR BOOST CONVERTER

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Sometimes, boost circuit feedback control is characterized by an unstable behavior. In literature different stabilizing or optimizing methods are proposed, based on voltage or current control. Switching curve method and sliding modes are among the best optimal procedures.

This paper presents a new method based on a linearized representation in phase plane and an interactively tuning procedure. Thus, this original approach enables a simple implementation with fast transients and stable behavior. Numerical results and interesting geometrical representations are presented.

Keywords: boost circuit, current control, switching curve, phase plane.

1. Introduction

The boost circuit is frequently used due to its simplicity and efficiency. It may be used either as a voltage source or, especially, as a current source. Regularly, the feedback loop acts on the duty cycle of the pulses which control the power switching element, taking into account the desired output current or voltage. PWM or hysteresis techniques may be used. These must satisfy stability criteria, which may be implemented by PI or PID methods. Different frequency domain representations are useful in order to determine the PI or PID parameters [4], [5]. Different liniarizing or Z transform methods may be used too.

On the other hand, sliding mode techniques are benefic due to the optimal characteristics which may be obtained, from certain points of view. This may be done for real conditions switching mode, with strong nonlinearities, without any approximations on physical phenomena.

At origins, sliding mode techniques are based on switching surface method, which has simpler geometrical interpretation. However, rigorous procedures imply a lot of mathematical background, which is applicable only for simple cases [1].

The paper presents a multi-switching line method, which work in a special context, defined by a multilevel reference voltage with sharp transitions, considering a known resistive load.

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2. The principle of the method

In general, sliding mode control is based on the classical concept of switching surface, represented in the phase space. This technique is described, from a mathematical point of view, in reference [1]. Theoretically, the switching surface may be multidimensional and has as coordinates a system parameter and different order of its derivative. Of course, a physical dynamical system is described by more parameters, linked by differential equations. Considering some assumptions, it can be shown that a high order differential equation is equivalent with a lower order system, which can be reduced to one. By this way, the phase space coordinates may represent just the system parameters.

In general, the switching surface is a curved one and may be represented by differential geometry equations. In order to determine these equations, often complicated symbolic calculations are necessary. Fortunately, the number of dimensions decreases with the number of parameters. When the number of phase coordinates may be reduces to two, the switching surface becomes a curve and the phase space becomes a plane.

When is constant, a desired value for a parameter acts as a reference, which must be reached by a system parameter, following an approximation process. This may be interpreted as a geometric or cinematic process, where the system state is represented by a generic point, which fallows an evolution trajectory, in order to reach a target point or an equilibrium point. This becomes the origin of coordinates, when an error signal is considered.

The situation is more complex when the desired parameter is a variable. Moreover, the determination of switching surface becomes very complicated in this context. A possible solution is a continuous dynamically translation of coordinate system origin, following the desired parameter variation, like in reference [6]. However the switching curve remains difficult to be determined, even in elementary cases representing, for example, simple electrical circuits.

Switching surface method gives best results if it may be rigorous defined by analytical methods. For best convergence results, the phase space coordinates must represent only a main parameter and its derivatives. Thus, when the equilibrium point is reached all the coordinates, except the main parameter, are nullified. This enables that the target point has a single non-null coordinate. This may be also nullified if the origin of coordinates is translated. Thus, the system must be controlled in order to go to origin.

If general system parameters are used, in the equilibrium point all the coordinates may be non-null. However, in this case too, the control may be achieved if the convergence speed of parameters is strongly different, as in [7].

When the switching surface is only approximated or different measurement or evaluation perturbation occurs, the trace did not follow the switching surface and a sliding mode takes place, as in [3]. Its parameters may be determined by different strategies in order to obtain process stability. However, these are functions of system parameters and overall optimality may not be obtained.

The paper describes a new method, that may be interactively or a-posteriori optimized. This works in parameters space, where the target point is represented explicitly by its coordinates. The switching curve, which is approximated by a straight line, is determined as slope and origin-ordinate using the given parameters and a single interactively tuned parameter. If unknown, the load may be determined by measuring or computing means. The interactively tuning may be replaced by a-posteriori testing procedures.

The new method, presented in this paper, is simple and direct. This is based on a problem context, when the desired parameter is a step variable. Thus, the switching curves may be approximated by straight lines, different for every step value of the desired parameter.

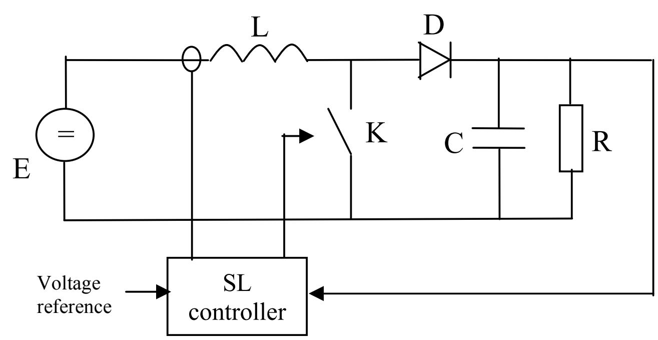

Fig.1. The current controlled boost

3. The mathematical model

The current controlled boost circuit is presented in Fig.1. In the classical optimal control theory context, the system evolution is determined by differential equations, whose coefficients depend on system characteristics and free terms depending on supply sources.

But, the actual considered mathematical model of the boost circuit does not follow this pattern. The switching element acts not on constant voltage sources, as in [7], but on the circuit topology, that is reconfigured at every switched state, as a variable structure system. Here the reference parameter is a step function. Each level defines a constant value of the reference voltage, corresponding to a target point.

The paper purpose a simple method, based on a linearization of the switching curve and an interactively tuning procedure, taking into account that a single tuning parameter is implied.

For continuous mode, considering as unknown parameters the inductive current and the capacitive voltage, two equation groups may be defined, corresponding to the states of K switch:

ec. group I: $L\frac{di(t)}{dt} = -R_1 \cdot i(t) + E \qquad C\frac{du(t)}{dt} = \frac{1}{R_2}u(t)$ (K=ON) (1)

ec. group II: $L\frac{di(t)}{dt} = -R_1 \cdot i(t) - u + E \qquad C\frac{du(t)}{dt} = i - \frac{1}{R_2}u(t)$ (K=OFF) (2)

When is fixed, the switching line may be represented by a coordinate dependent function with coefficients α_1 and α_2 and denoted as:

$$S = \alpha_1 \cdot x_1 + \alpha_2 \cdot x_2 \qquad (3)$$

where x_1 and x_2 are coordinates in phase plane.

When S has different positions, which may vary with time, it may be determined by its slope P(t) and ordinate N(t), parameterized with time:

$$\mathrm{S(t)} = \mathrm{P(t)} \cdot (u^{<k>})_0 + N(t) \qquad (4)$$

The control strategy is defined at every moment by the sign of S function, corresponding to an instance of state equations group and switch K state, as following:

if (S > 0) then K ≡ On and equations of group I are valid;
if (S < 0) then K ≡ Off and equations of group II are valid.

The switching line parameters are determined using the following rules:

- the slope is determined interactively. When optimal, the switching line should pass through the point defined by the first intersection of evolution trajectory and the real switching curve, as it should be known.
- the ordinate computed with condition that the switching line must pass through the target point.

Considering the last condition, combined with the straight-line equation the following relation may be written for the ordinate N(t):

$$N(t) := U(t) - P(t) \cdot \frac{1}{E}\frac{U(t)^2}{R(t)} \qquad (5)$$

where $\left(\frac{1}{E}\frac{U(t)^2}{R(t)}, U(t)\right)$ are current and voltage coordinates of the target point, with known values for load R(t), supply voltage E and reference voltage U(t). During simulations the slope P(t) is tuned interactively, until the desired stability and optimality characteristics are obtained. Then, these obtained values may be used in real time operation.

Here, for computational purposes, the algorithm uses the MathCad language representation. This enables recursive vectorial form and compact relations derived from the circuit equations. The procedure algorithm may be represented recursively with the vectorial equation (6).

The new state vector, denoted as $\mathbf{u}^{<k+1>}$, has three components which are given in the left site. The first two expressions calculate the new parameters values for current and voltage, represented by the first two coordinates of vector **u**. Each is defined by two sub-expressions, which are chosen, depending on the third component of **u**, corresponding to the relative position of the generic point against the switching line. Using "if" conditional statements, the equations corresponding to K switch states may be combined. The third component is a binary control variable, which determines the reconfiguration of the equations, when the phase plane trajectory crosses the switching line.

$$u^{<k+1>} := \begin{bmatrix} (u^{<k>})_0 + h \cdot if\left((u^{<k>})_2 = 1, \frac{1}{L}\cdot E, -\frac{1}{L}\cdot(u^{<k>})_1 + \frac{1}{L}\cdot E\right) \\ (u^{<k>})_0 + h \cdot if\left((u^{<k>})_2 = 1, -\frac{1}{R(t_k)\cdot C}(u^{<k>})_1, \frac{1}{C}(u^{<k>})_0 - \frac{1}{R(t_k)\cdot C}(u^{<k>})_1\right. \\ if\left((u^{<k>})_1 < P(t_k)\cdot(u^{<k>})_0 + N(t_k), 1, 0\right) \end{bmatrix} \quad (6)$$

The variables have the following significance:

R, L, C, E - circuit component values and voltage supply;
h - time step value;
t_k - discrete time variable;
$P(t_k)$ - instantaneous switching line slope;
$N(t_k)$ - instantaneous switching line ordinate;
$u^{<k+1>}$ - next state vector parameter;
$(u^{<k+1>})_0$ - 0-component - corresponding to inductance current value;
$(u^{<k+1>})_1$ - 1-component - corresponding to capacitor voltage value;
$(u^{<k+1>})_2$ - switching binary variable.

4. Simulation results

The simulated evolutions of inductive current and capacitive voltage, for a step variable reference voltage, are showed in Fig.2. The $(u^{<k>})_0$ vector component represents the current variation and $(u^{<k>})_1$ component represents the voltage variation. It must be mentioned that the optimization criterion concerns the fastest stabilization to the reference value. Thus, current and voltage overshoots are expected.

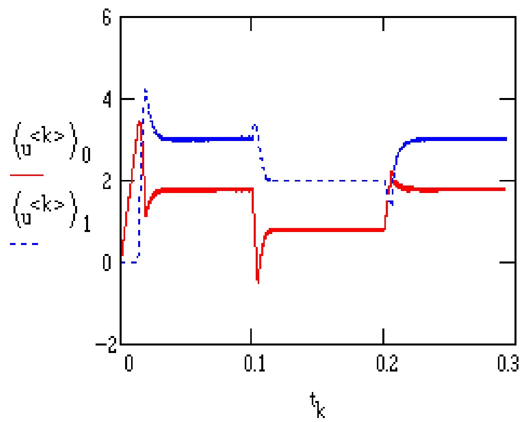

Fig.2. Voltage and current evolution

Fig. 3 shows the phase plane geometrical representation for the parameters evolution, determined by the presented method. The figure contains the following elements, generated in a discrete way and plotted point by point, using MathCad *k* indexed variables.

- Evolution trajectory, whose generic point is defined by inductive current and capacitive voltage instantaneous values with coordinates $(u^{<k>})_0$, $(u^{<k>})_1$;
- The three switching lines, corresponding to the first three values of reference voltage, with points defined by the following coordinates: $(DX1_k, DY1_k)$, $(DX2_k, DY2_k)$, $(DX3_k, DY3_k)$.
- The target points placed at line intersections with abscissas corresponding to computed currents I1, I2, I3 and ordinates corresponding to given voltages: U1, U2, and U3. In order to plot the line variations, auxiliary variables Ox and Oy, covering whole variation range, are used.

Starting at (0,0) the evolution trajectory, after the first intersection with every switching line, is going to corresponding target point, this having an accumulation point behavior.

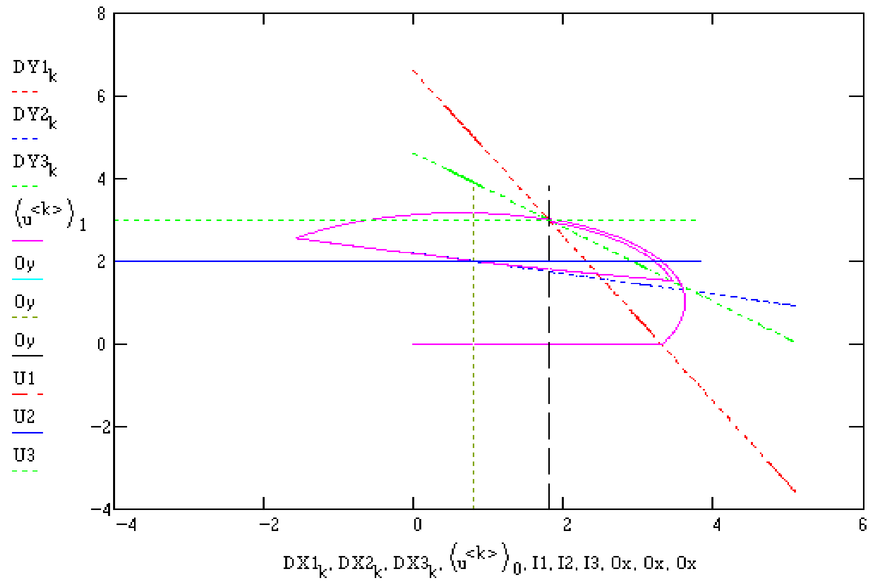

Fig.3. Gobal geometrical representation.

The fine sliding mode processes, quite unobservable, are detailed in Fig.4, 5 and 6, for the three reference values and corresponding target points (I1,U1), (I2,U2) and (I3,U3). In each case, is represented the corresponding switching line, determined by (X_k,Y_k) local coordinates. Due to the convergence process, the computation steps become smaller when the generic point is closer to the target point, represented as a pointed lines intersection.

It must be mentioned that, if the slope of the switching line is not tuned for fastest convergence, although stability is obtained for current controlled mode, a longer sliding mode process occurs, as in Fig.7.

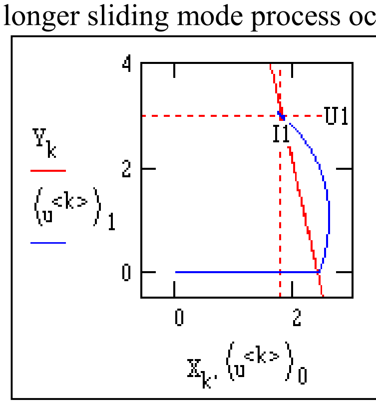

Fig.4. First acumulation point

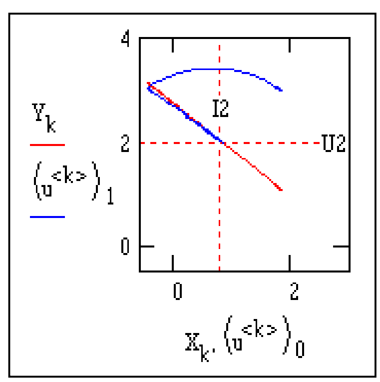

Fig.5. Second acumulation point

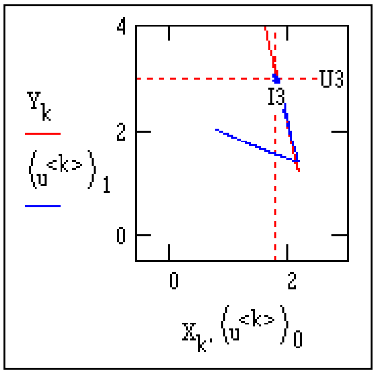

Fig.6. Third acumulation point.

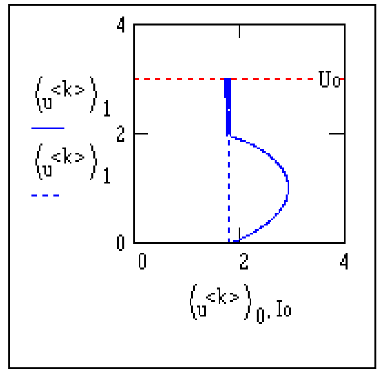

Fig.7. Non-optimal approximation process.

5. Conclusions

The paper describes a new method for current controlled boost circuit. Personal contribution concerns the geometrical representation of boost circuit evolution and linear control method with an interactive optimization based on a single parameter. Comparing with other known methods, the geometrical representation enables to work directly with reference target point coordinates, without considering an error signal. This is possible due to the resistive load, with a known or measurable value during the control process. The optimum is stated by interactively or heuristic determinations of switching line slope, obtaining both fastest operation and stability characteristics. These lead to a simple control procedure, based on simple arithmetical operations. These may be implemented by low cost controllers or basic analogical circuits.

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