Sliding Electronic Method to Control a Thermoelectric Device

Antonio M. López- Javier Villasevil - Germàn Noriega
Departamento Ingeniería Electrónica - Universitat Politècnica de Catalunya
E.P.S.E.V.G. Av. Victor Balaguer s/n, Vilanova i la G. 08800
Email: lopezm@eel.upc.es - villasevil@eel.upc.es – cidete@arrakis.es
Phone: 938967728 – 938967762 Fax: 938967700

Abstract

The precise temperature control for a thermoelectric device requires of precise power supplies.

The nature of the load that is variable with the internal temperature, as a generator and the external temperature, depending on the ambient in were is located, should be connected to special power supplies for such purpose. Actually the switching power supplies that work from direct to direct conversion with new commute techniques seams to be the right solution because of its high efficiency, low weight and high reliability. Nevertheless the conventional power supplies are characterize for their losses in the switching working mode, of the switches specially in applications of high power as in the thermoelectric devices.

The high currents and voltages and the losses of the commute elements in the power supplies will extremely limit the internal working frequency and the electromagnetic interferences.

The resonance converters seam to be an acceptable solution, but because of its characteristics they show an increment of the losses of the switching mode and conduction that lead to a fast deterioration in this structures.

In this work, it will be study a control sliding technique in a switching power supply from direct to direct "Buck", to which is apply as a load a thermoelectric device and using an equivalent simple model. It has been develop according to the Lyapunov method, to obtain a sliding surfaces in the switching mode to assure the complex stability of the system form by the converter and the load.

Introduction

The typical structure of the system in blocks with its load is shown in the figure 1.

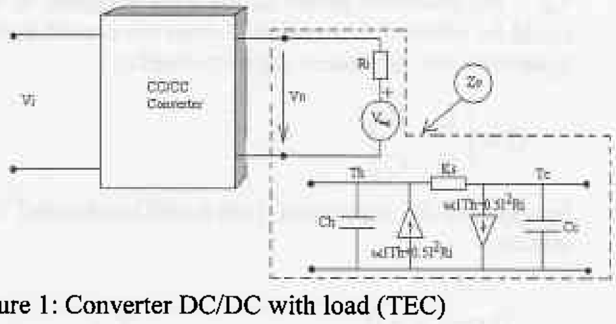

Figure 1: Converter DC/DC with load (TEC)

In the basic scheme of a converter "Buck" is shown in the figure 2.

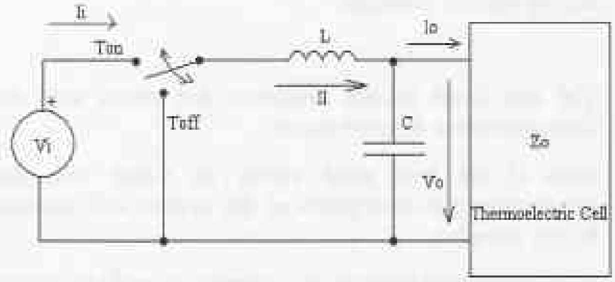

Figure 2: Structure of the Power.

A converter DC-DC vary in a switching cycle with different topologies.

It could be describe each topology through a differential equation of stage. In the converter given in the figure 2, and for a continues conduction it is shown two different topologies in a switching cycle between Ton and Toff of the physical switch as they could be describe in a general way as:

$$\dot{x}(t) = A_1 \cdot x(t) + B_1 \cdot u(t) \quad \text{for} \quad 0 \leq t \leq \text{Ton} \qquad (1)$$

$$\dot{x}(t) = A_2 \cdot x(t) + B_2 \cdot u(t) \quad \text{for} \quad \text{Ton} \leq t \leq \text{Toff} \qquad (2)$$

If it is being chose as state variables the inductance of the current L, is to say I1 and the output voltage Vo, then the matrix A_1, B_1, A_2 y B_2 could be define as:

$$A_1 = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{C \cdot Z_o} \end{bmatrix} \qquad B_1 = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{C \cdot Z_o} \end{bmatrix} \qquad B_2 = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \qquad (3)$$

If the working cycle is define as $D=\dfrac{Ton}{T}$ the global solution to the state equations (1) and (2) could be express as a differential equations:

$$\begin{aligned} & x(T)=e^{A_2(1-D)T}\cdot e^{A_1DT}\cdot x(0)+ \\ & +(e^{A_2(1-D)T}\cdot A_1^{-1}\cdot\left[e^{A_1DT}-[1]\right]\cdot B_1+ \\ & +A_2^{-1}\cdot\left[e^{A_1(1-D)T}-[1]\right]\cdot B_2)\cdot u \end{aligned} \tag{4}$$

The expression (4) is a non lineal equation in the working cycle regulation that is always vary and also the working frequency could also vary by using the sliding surface methods.

The non lineal system converter that varies with the time and with a discrete signal.

Also if the load used varies its value with the temperature the description of the system will become highly complex.

With the second method of Lyapunov it could be obtain information about the stability of the system through a function definition V(x,t) , that is define as positive, as not in the initial point that its value is 0. with the derivate W(x,t) , that is define as negative in a stable system.If the state variable is define with increments as the difference between instantaneous values of the variables and the equilibrium point:

$$\begin{aligned} \Delta x &= x-x_0 \\ \Delta u &= u-u_0 \end{aligned} \tag{5}$$

being the equilibrium point x_0:

$$x_0=-B\cdot u_0\cdot A^{-1} \tag{6}$$

the given system by their state equations (1) and (2), could be express in general way as function of the variables with increment as:

$$\dot{\Delta x}=A\cdot\Delta x+B\cdot\Delta u \tag{7}$$

The function V(x,t) from Lyapunov as function of the incremented variables should be value as a quadratic form:

$$V(\Delta x)=\frac{1}{2}\cdot\Delta x^T\cdot Q\cdot\Delta x \tag{8}$$

were Q is a symmetric matrix define as positive:

The derivate of the function $V(\Delta x)$ is:

$$V'(\Delta x)=\frac{1}{2}\cdot\Delta x^T\left(QA+A^TQ\right)\cdot\Delta x+BQ\cdot\Delta x\cdot\Delta u \tag{9}$$

that will be negative if all the terms of the expression (9), are negative.

Starting from the define previous expressions it could be design a control strategy of the switching power supply based in sliding surfaces in such way that:

$$S=-B\cdot Q\cdot\Delta x \qquad u=\begin{cases}1, \text{si } S>0\\ 0, \text{si } S<0\end{cases} \tag{10}$$

being S the generalize sliding surface and the input digitalize system.

Implemetation in the Buck converter

Considering the circuit in the figure 2 the bi-lineal model could be describe with the following matrix with the state variables of the current of the inductance i_L , and the output voltage v_0, considering as load the thermoelectric device with value

$$z_0: \dot{x}=\begin{pmatrix}\dfrac{di_L}{dt}\\ \dfrac{dv_0}{dt}\end{pmatrix}=\begin{pmatrix}0 & -\dfrac{1}{L}\\ \dfrac{1}{C} & -\dfrac{1}{C\cdot Z_0}\end{pmatrix}\cdot\begin{pmatrix}i_L\\ v_0\end{pmatrix}+\begin{pmatrix}\dfrac{v_i}{L}\\ 0\end{pmatrix}\cdot u \tag{11}$$

and if we use variables with increment in the steady state function we will obtain the following expression:

$$\dot{\Delta x}=\begin{pmatrix}\dfrac{d\Delta i_L}{dt}\\ \dfrac{d\Delta v_0}{dt}\end{pmatrix}=\begin{pmatrix}0 & -\dfrac{1}{L}\\ \dfrac{1}{C} & -\dfrac{1}{C\cdot Z_0}\end{pmatrix}\cdot\begin{pmatrix}\Delta i_L\\ \Delta v_0\end{pmatrix}+\begin{pmatrix}\dfrac{v_i}{L}\\ 0\end{pmatrix}\cdot\Delta u \tag{12}$$

To be able to develop the second law of Lyapunov in this case it must be consider a state variable in steady state.

The impedance z_0, related to the thermoelectric structure, is consider as constant and resistant in a first approach which will show that ΔT, must be constant.

In the assumption of this hypothesis and considering i_{L0} and v_{o0}, the reference points of the state variables in increment could be selected as a matrix Q from the second method from Lyaponov the inductance capacity matrix:

$$Q=\begin{pmatrix}L & 0\\ 0 & C\end{pmatrix} \tag{13}$$

by applying the expression (10) it Hill be obtained the sliding surface:

$$u=\begin{cases}1 \text{ con } S>0\\ 0 \text{ con } S<0\end{cases} \qquad S=i_L-\frac{V_{o0}}{Z_o} \tag{14}$$

There is the inconvenience output impedance dependence variations (thermoelectric device) with the control surface. To avoid this inconvenience and independent the function S of the load it could be added a new state variable in (12) that include an integrated term to minimize the fault of the output voltage.

Some how, if we take into consideration a much more real model of the load as a thermoelectric device in which we can appreciate the Seebeck voltage V_α, the description with state equations will vary.

$$\frac{di_L}{dt} = -\frac{1}{L}\cdot v_o + \frac{1}{L}\cdot v_i$$

$$\frac{dv_o}{dt} = \frac{1}{C}\cdot i_L - \frac{1}{C\cdot R_i}\cdot v_o + \frac{1}{C\cdot R_i}\cdot v_\alpha$$

(15)

or well.

$$\dot{x} = \begin{pmatrix} \frac{di_L}{dt} \\ \frac{dv_0}{dt} \end{pmatrix} = \begin{pmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{C\cdot R_i} \end{pmatrix} \cdot \begin{pmatrix} i_L \\ v_0 \end{pmatrix} + \begin{pmatrix} \frac{v_i}{L} \\ \frac{v_\alpha}{C\cdot R_i} \end{pmatrix} \cdot [u \quad 1]$$

(16)

and its expression with increments is:

$$\Delta\dot{x} = \begin{pmatrix} \frac{d\Delta i_L}{dt} \\ \frac{d\Delta v_0}{dt} \end{pmatrix} = \begin{pmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{C\cdot R_i} \end{pmatrix} \cdot \begin{pmatrix} \Delta i_L \\ \Delta v_0 \end{pmatrix} + \begin{pmatrix} \frac{v_i}{L} \\ \frac{v_\alpha}{C\cdot R_i} \end{pmatrix} \cdot [\Delta u \quad 1]$$

(17)

were R_i is the equivalent resistance in the semiconductors. As Como $v_\alpha = \alpha\cdot\Delta T$ being ΔT, the temperatura difference from the hot T_h, and the cold face T_c, of the thermoelectric device and α, the Seebeck coefficient, the equation (16) could be express as:

$$\Delta\dot{x} = \begin{pmatrix} \frac{d\Delta i_L}{dt} \\ \frac{d\Delta v_0}{dt} \end{pmatrix} = \begin{pmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{C\cdot R_i} \end{pmatrix} \cdot \begin{pmatrix} \Delta i_L \\ \Delta v_0 \end{pmatrix} + \begin{pmatrix} \frac{v_i}{L} \\ \frac{\alpha\cdot\Delta T}{C\cdot R_i} \end{pmatrix} \cdot [\Delta u \quad 1]$$

(18)

Applying the expression (10) it is possible to obtain sliding surface and the identical control law in the process to obtain the expression (14), and to obtain:

$$S = i_L - \frac{V_{o0}}{R_i} + \frac{\alpha\cdot\Delta T}{R_i} \quad \text{con} \quad u = \begin{cases} 1 \text{ con } S > 0 \\ 0 \text{ con } S < 0 \end{cases}$$

(19)

The practical application of the describe law in (19) is complex because it depends direct from the variables of the load. If it is consider constant α, ΔT and R_i, the practical solution is much more simple.

In a block diagram of the sliding surface, found within the control law, it could be observe in the figure 3.

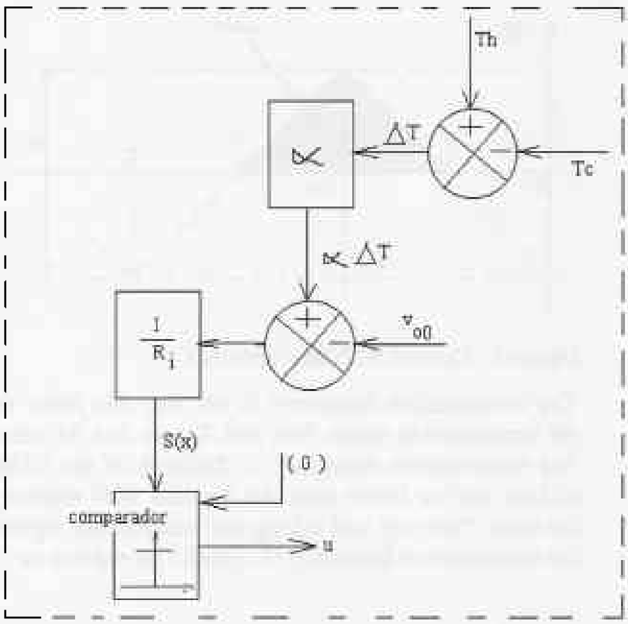

Figure 3: Simplify scheme control

The control system with sliding surface methods S(x) and the control function (u) , with the switching structure of the power supply in the figure 2, will be shown in the figure 4.

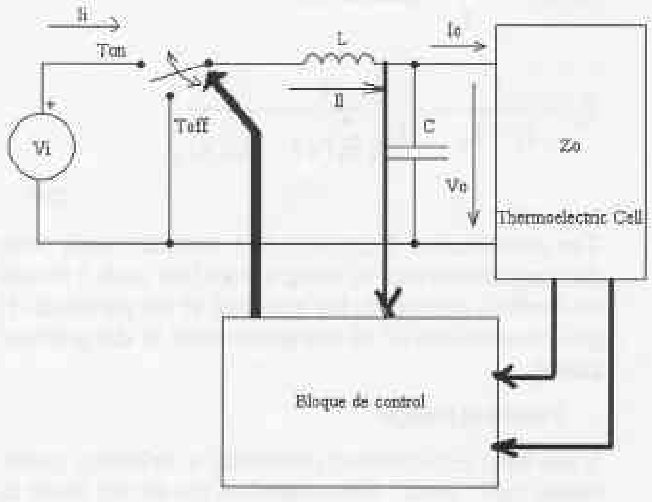

Figure 4: Power Block and Control

It is important to observe that the commute frequency is variable and it is not a control base in the pulse width (PWM). As a fact with this control strategy it is forced that the state variables will be lead to sliding surface design for such purpose.

It is possible to improve the behaviour of the system in front of a transitory respond by adding an integrated term in the sliding surface that will softer the system in front of disturbance sudden and fast.

The sliding surface founded as the expression (19) follow approximately the variations of the current in the condenser C of the switching power supply that is represented in the figure (5).

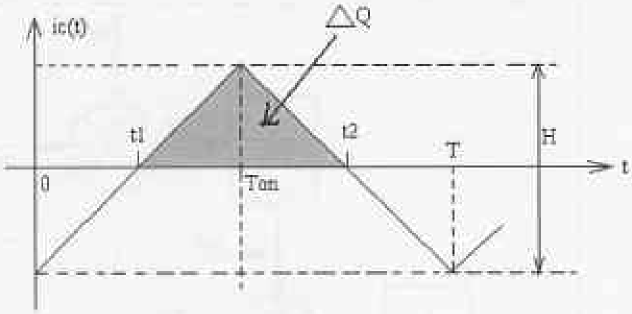

Figure 5: Current with the capacity C

The commutation frequency is not fix, this jeans that the commutation times Ton and T are not fix either. The commutation frequency is function of the sliding surface S(x) or better than the derivate with respect to the time. This way and taking into account the figure 5 the commutation frequency (Fc) could be express as:

$$t_4 = T_{on}$$

$$t_5 = T - T_{on}$$

$$\dot{S}_1(x) = \frac{H}{t_4} \quad \text{cuando } u = 1$$

$$\dot{S}_0(x) = -\frac{H}{t_5} \quad \text{cuando } u = 0$$

$$F_c = \frac{1}{t_4 + t_5} = \frac{1}{H} \cdot \left(\frac{1}{\dot{S}_1(x)} - \frac{1}{\dot{S}_0(x)} \right) \tag{20}$$

The commutation frequency (Fc) depends much from the comparative that its being use and for such it should be carefully observe in the selection of the parameter H and its reliability of its implementation in the practical circuit.

Practical Design

It has been implemented practically a switching power supply type "Buck" with control of the slicing mode as the method describe, with deference to the slicing surface and the control function.

Given by the expression (19). It has been done with conventional components with out involving and programmable option in the control block. As load it was use a thermoelectric device 8 amps and 12 volts. In the figure 6 it could be observe such power supply with its load.

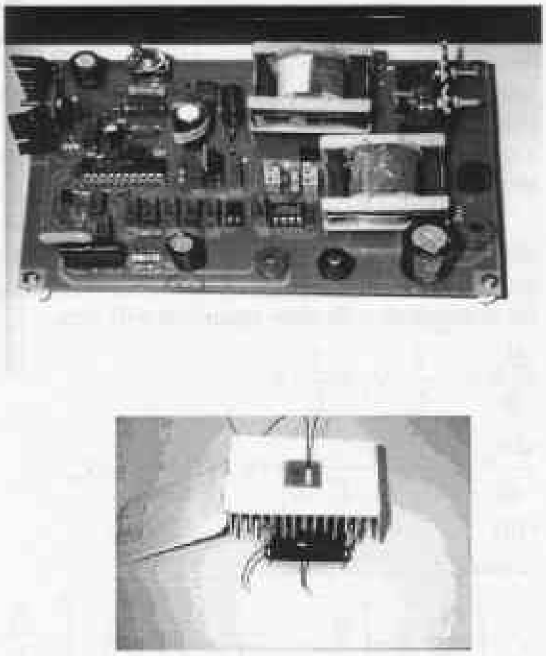

Figure 6: Switch Regulator with its load (TEC)

Conclusions

It has been developed a control unit for a switching power supply base in sliding surface that adds stability and reliability to the system avoiding unexpected transients.

It has been build a practical application that confirm the theoretical expressions.

It is possible to improve its dynamical behaviour with some modifications on the sliding surface that take into account and integrated term and implementing the system with a programmable options as µC and FPGA.

References

[1] G.N. Logvinov , Yu V. Drogobitsky , Yu. G. Gurevich , A. F. Carbalo , O. Yu. Titov
Unsteady - State Thermoelectric Respose For a Thermal Pulse in Semiconductors
Proceeding, XVI ICT 97 , Dresden, Germany, 1997, pp. 749 - 752

[2] B.Nicolas, M.Fadel and Y.Cheron , "Sliding Mode Control of DC to DC Converts with Input Filter Based on the Lyapunov Function Approach", 6th European Conference on Power Electronics and Applications, pp.1338-1343,September 1995.

[3] K. Ogata , "Modern Control Engineering", Prentice Hall, 1996.

[4] S.R.Sanders and G.C. Verghese "Lyapunov-Based Control for Switched Power Converters", IEEE. Trans. On Power Electronics, vol. 7, no. 1, pp. 17-24, January 1992