INVERSE MODEL OF DC-DC CONVERTERS

István Dénes[1] Péter Baranyi[2]

[1] Budapest University of Technology and Economics,
Department of Automation and Applied Informatics
e-mail: pityu2@goliat.eik.bme.hu

[2] Assistant professor, Budapest University
of Technology and Economics, Department of
Telecommunication and Telematics

Abstract: This paper describes the control of quasi-resonant converters. Because of control difficulties caused by the high nonlinearity of converter components, an adaptive fuzzy control algorithm is proposed. The results of computer simulation is presented to show the effectiveness of the proposed control.

Keywords: Converters, Fuzzy control, Control algorithms, Computer Simulation

1 INTRODUCTION

In this paper a control method is discussed for a resonant step-down converter. The main favorable features of the quasi-resonant switching converters are greatly reduced switching stress and loss in switching devices, high or ultra high switching frequency, with high bandwidth, good efficiency, high power density and considerable size and weigh reduction (Nagy, 1989). Because of their nonlinear operation, an adaptive fuzzy system is applied as a control device.

The area of fuzzy modeling and identification has developed significantly in recent years. Techniques were introduce to construct fuzzy models using expert knowledge, as well as measurements (Takagi and Sugeno 1985, Yager and Filev in 1994, Pedryz in 1995). Once a fuzzy model of a system under consideration is available, it can be used for various goal, such as analysis, prediction or controller design. A class of dynamic systems can be effectively controlled by inverting the process model using for instance the nonlinear internal model control (IMC) scheme (Morari, Zafirioru, 1989). An inverse model can also be used off-line to help a human operator to find appropriate actions to control the process. However only limited attention has been paid in the literature to the inversion of fuzzy models. Among the first, the application of inverse fuzzy model appeared in open loop controllers (Babuska, 1996). At the same time, fuzzy inversion processes had spread also in feedback loop controllers. Control units based on forward prediction (Predictive Model Control, PMC), had shown promising results (Tong, 1978 , Pedryz, 1984 , Sugeno, 1985,...), in industrial, (Camacho, 1995, Linkers, 1994), and in other type of applications (Garcia, *et al.*, 1989). In this area controllers exist, designed by algorithms, based on the inversion of the fuzzy model. Controllers are often created, by direct tuning, upon measurements of the real system, so application of the fuzzy inversion is not reasonable in each case.

Significance of model inversion inspired the development of many processes in fuzzy fields. Pedryz (1990) worked on the inversion of fuzzy relation. Applying gradient method, Nomura developed processes in 1991. Fisher (1998) had implemented analytic solutions for special fuzzy models and cases. At this analytic process, the inverse was calculated, based on the inversion of the fired rules in the original fuzzy rule base. Várkonyi-Kóczy published an algorithm in 1998 which approximates the inverse model by iterative steps. Baranyi (1997) proposed a method in 1997 capable of generating exact inverse model off-line. It is a real fuzzy to fuzzy inverse operation.

2 CONVERTER CONFIGURATION AND OPERATION

The configuration of a resonant buck converter is shown in **Fig. 1**. The switches can conduct current only into one direction shown by arrow.

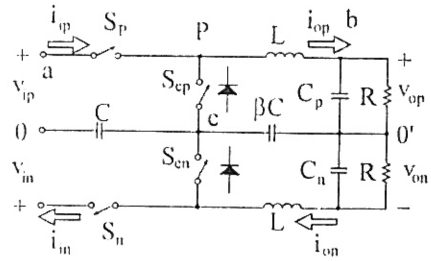

Fig. 1 The converter configuration

2.1 Operation (Nagy, 1989)

For the sake of simplicity a reduced circuit will be treated. Capacitor βC was substituted with a shortcut and switch S_{cp} and S_{cn} were changed to diodes.

After turning on S_p, a voltage swing develops across C by the positive current pulse i_c. i_c flows in the ringing circuit V_{ip}-S_p-L-V_{op}-C. When v_c reaches V_i, it blocks current conduction in S_p at angle α and turns on diode D_p. v_c has started from v_c=-V_i at ωt=0 (Fig. 2). From angle α on the energy trapped in the choke is depleted by ramp like diode current i_{Dp}. The same process takes place in the other half of the configuration resulting a negative current pulse and condenser voltage swing after turning on S_n at the beginning of the next half cycle $\omega T_s/2$. The choke current is discontinuous in Fig. 2. Assuming continuous choke current, there is a second current commutation now from diode to S_p at $\omega t=\omega T_s/2$ as well in addition to the first one taking place from S_p to diode. The voltage across S_p is zero either in continuous or in discontinuous mode at turn on or turn off period.. For this reason the converter is called Zero Voltage Turn-off (ZVT) quasi-resonant converter.

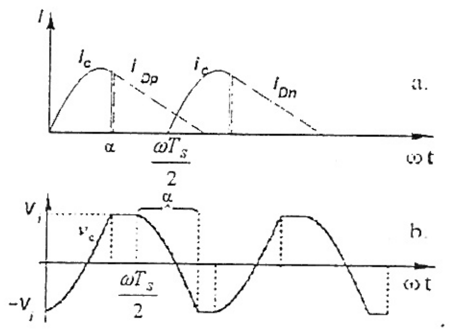

Fig. 2 Voltage, current waveforms

The describing equations:

1. If S_{cp} is on and $V_c<V_i$

$$-V_i + L\frac{di}{dt} + \frac{1}{C_p}\int idt - \frac{1}{C}\int idt = 0 \quad (1)$$

2. If S_{cp} is on and $V_c>V_I$

$$L\frac{di}{dt}+\frac{1}{C}\int idt=0 \qquad (2)$$

Although (1), (2) are linear describing equations their applicability depends on the current state of switches and diodes. This behavior gives a strong non-linearity to the system. This strong non-linearity is the reason why the control of the converter is based on a fuzzy approach.

3 THE FUZZY THEORY

3.1 n-variable PSGS (Product Sum Gravity) algorithm

Antecedent sets: *Ruspini* partition fuzzy sets
Consequent sets are singleton sets.
Rules: If $A_{1,i1}$ and ... and $A_{n,in}$ then $B_{i1..in}$
y^* the deffuzificated value of B conclusion.
In case of *Ruspini* partition sets:

$$y^*=\frac{\int y\mu_{B^*}(y)dy}{\int \mu_{B^*}(y)dy}=\sum_{i1=1}^{n1}\dots\sum_{in=1}^{nn}\left(y_{i1\dots in}\prod_{i}^{n}\mu_{A_{i,ii}}(x^*_i)\right)$$

(3)

3.2 The inversion of n variable rule base, in case of optional number of rules

The rules of the given rule base: If $A_{1,i1}$ and...and $A_{n,in}$ then B_m,

$$m=j_n+\sum_{l=1}^{n-1}(j_l-1)\prod_{r=l+1}^{n}n_r \,. \qquad (4)$$

The original rule base should be split to

$$\prod_{i+1}^{n}(n_i-1) \qquad (5)$$

number of rule basis, where the number of rules are 2^n, and the antecedent sets are $A_{i,ii}$ and $A_{i,(ii+1)}$,i_i=1..(n_i-1). The t^{th} rule base should be signed by RB_t,

$$t=1..\prod_{i=1}^{n}(n_i-1)\,. \qquad (6)$$

The rules are If $A_{1,j1}$ and ... and $A_{n,jn}$ then

$$B_m,\ m=j_n+\sum_{l=1}^{n-1}(j_l-1)\prod_{r=l+1}^{n}n_r,(j_i=1..2) \quad (7)$$

core($A_{1,1}$)<core($A_{1,2}$). The inverted rule of RB_t : the inverted rules in the rule base: If B_{j1} and $A_{2,j2}$ and .. and $A_{n,jn}$ then $A_{1,k}$

$$k=j_n+\sum_{l=1}^{n-1}(j_l-1)\prod_{r=l+1}^{n}n_r,\forall i:n_i=2\,. \quad (8)$$

In the rule base the antecedent sets on the X_i, i=2..n input base set are the same as at the original rule base. At the Y input base set should be normal triangle sets in *Ruspini* partition, the way that core(B_1) is the minimum of the of the cores of consequent sets of the original rule base:

$y_{min}=\min_m(y_m)$, $\quad y_m$=core(B_m) $\quad$ and

$core(B_2)=y_{max}=\max_m(y_m)$.

The core of the k^{th} consequent set is core($A_{1,k}$)=d_k and the size of the support is z_k, then:

$$z_k=(y_k-y_{min})s_k+(y_{min}-y_{k+1})s_{k+1};$$

$$z_{k+1}=(y_k-y_{max})s_k(y_{max}-y_{k+1})s_{k+1}$$

$$d_k=\frac{(y_1-y_{min})x_{1,2}s_k+(y_{min}-y_{k+1})x_{11}s_{k+1}}{(y_k-y_{min})s_k+(y_{min}-y_{k+1})s_{k+1}};$$

$$d_{k+1}=\frac{(y_k-y_{max})x_{1,2}s_k+(y_{max}-y_{k+1})x_{1,1}s_{k+1}}{(y_k-y_{max})s_k+(y_{max}-y_{k+1})s_{k+1}}$$

(9)

Using inverted rule base at a given observation, every t^{th} rule base which contains the fired rules, the $x^*_{1,t}$ output value can be calculated. Among these values, the correct one, which belongs to the t^{th} rule base lies in the [$x_{1,1}$, $x_{1,2}$] interval.

4 THE IMPLEMENTATION OF THEORY IN THE CONVERTER CONTROL.

The aim was to create a fuzzy control unit, which is capable of keeping the output voltage on the value of V_{oid} reference signal under any load changes. References (Baranyi, 1997, Baranyi 1998) describe the theoretical bases of fuzzy control methods. The control process can be separated into three steps.

4.1 The learning phase

Fig. 3 shows the block diagram of the system. The signal generator provides switching frequency to the converter. The output voltage of the device is measured, along with the load current. From these quantities the fuzzy adaptation unit creates a voltage via frequency and load (current) function. In order to receive an accurate surface the adaptation process was corrected with an edge boost formula. (Dénes 1998)

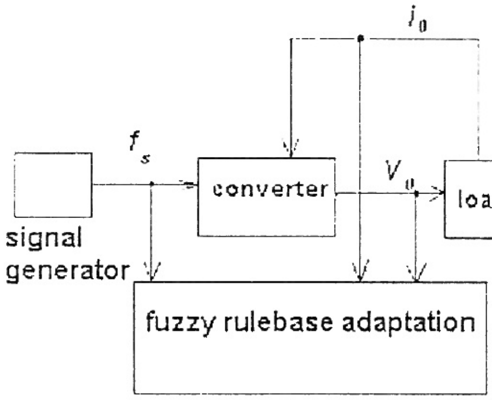

Fig. 3 The fuzzy rule base adaptation

4.2 Inversion (Fig. 4)

As to a next step a partial inversion of the function is needed in order to obtain a control surface. To invert the surface this paper proposes a practical extension to obtain a rulebase that fits the necessary condition of the inversion algorithm. The inverting step using the method published by the Baranyi in 1997 .

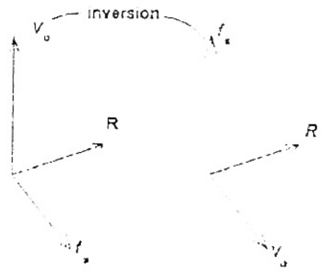

Fig. 4 The inversion procedure.

4.3 Control

By using the control surface grid points, the operation parameter (switching frequency) is determined (Fig. 5) PSGS algorithm.

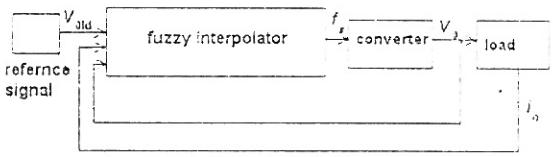

Fig. 5 The fuzzy control

5 RESULTS OF COMPUTER SIMULATIONS

After the construction of the control circuit simulations have been carried out in order to test the behaviour of the controlled converter.

The parameters of the converter selected as follows.

$C_o = 100\mu F$

$C = 100nF$

$L = 100\mu H$

$V_i = 100V$

Checking if the operation point is in the DCM region

Let the output voltage $V_o = 50V$, in this case the switching frequency at steady state $F_s = 12500Hz$ (Nagy, 1989).

The DCM operation is guarantied under $f_d = \frac{1}{T_d}$ switching frequency.

$$T_d = f_r\left(\frac{1}{2\pi}\frac{1}{\cos\left(\frac{A-1}{A+1}\right)} + \frac{1}{\pi}\frac{\sqrt{A}}{1-A}\right) \qquad (10)$$

where

$$f_r = \frac{1}{2\pi\sqrt{LC}} =$$

$$= \frac{1}{2\pi\sqrt{100*10^{-6}*100*10^{-6}}} = 52.6KHz$$

(11)

the commutation angle α

$$\cos\alpha = \frac{-V_o}{2V_i - V_o} = \frac{-50}{150} = -0.33 \qquad (12)$$

and

$$A\frac{1+\cos\alpha}{1-\cos\alpha} = 0.5 \qquad (13)$$

from (8)

$$T_d = 1.9*10^{-5}\left(\frac{1}{2\pi}\frac{1}{\cos\left(\frac{-0.5}{1.5}\right)} + \frac{1}{\pi}\frac{\sqrt{0.5}}{1-0.5}\right) =$$

$$= 1.15*10^{-5}s$$

(14)

$$f_d = \frac{1}{T_d} = 86.39Khz > F_s = 12.5KHz$$

That is the operation point is set in the DCM region.

First, a voltage step was given in the input of V_{ref} Fig. 6 shows the response of the system with fuzzy control.

In case of simulation 2 the reference voltage has been changed step-like three times and the following properties of the control has been tested. The load resistance has been fixed to $R = 100\Omega$.

At the third simulation, the goal was to keep a constant output voltage level (50V), while the output load was changing in three steps. Fig. 8 shows the results.

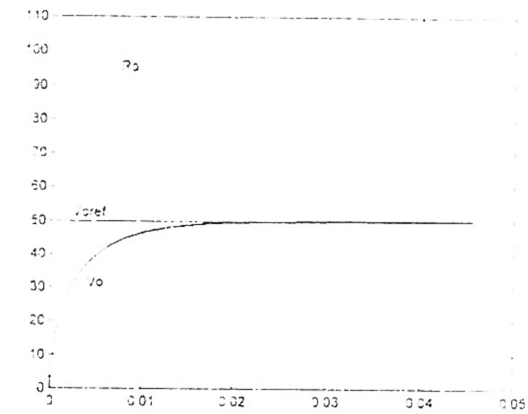

Fig. 6 The results of simulation 1

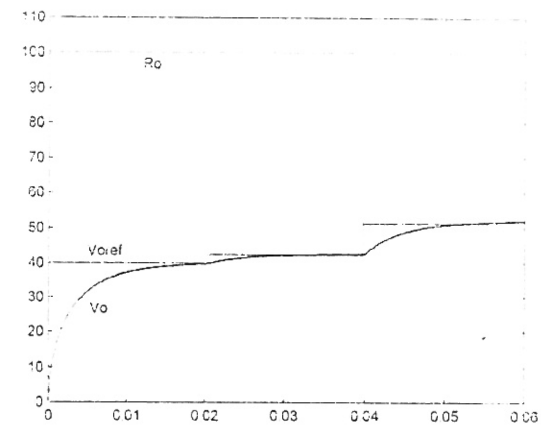

Fig. 7 The results of simulation 2

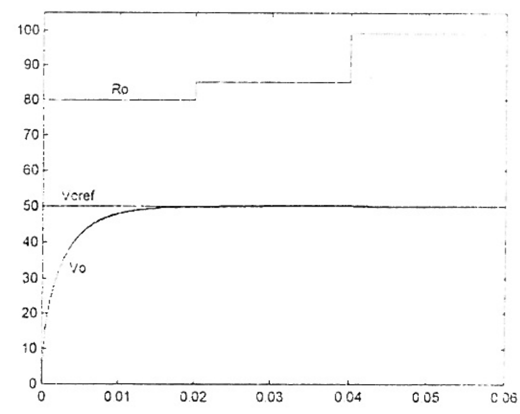

Fig. 8 The results of the simulation 3

6 CONCLUSION

Effectiveness of fuzzy control technique based on the inverse of approximated model, is proved through results of simulation. The speed of this control technique makes possible to apply it on fields, where the performance of the conventional controls are not adequate. Although computer simulations show promising results, the real speed of the fuzzy control highly depends on the applied hardware components.

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