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Comparison between software and hardware control in PSM mode of a Buck converter

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Abstract: The control of a DC-DC converter is generally done through a circuit comprising logic and analog components. In the presented work, we have ordered a Buck converter in two different ways. The first method consists in using a control in the form of an electrical circuit . The second method is based on the control of the converter through a programmable circuit. The program introduced in the form of a MATLAB embedded function and simulated under SIMULINK / MATLAB gave results similar to those obtained using the control made with a conventional electrical circuit. For the control, we chose the PSM mode (Pulse Skipping Modulation). It is an efficient and simple control to realize both in the form of an electrical circuit and under programming. The comparison of the results obtained under SIMULINK / MATLAB enabled us to highlight the advantages and disadvantages of each method.

Keywords: Buck Converter, PSM Mode, Programmable control, MATLAB embedded function.

I. INTRODUCTION

Static converters are generally based on power electronics components used as switches. They have a control circuit which must act on the opening or closing of the switch according to a well-defined protocol and frequency. These control devices are implemented in the form of analogue or digital circuits. At the present time, we are moving towards a programmed control which is managed by a programmable logic circuit.
The advantage of this method is its simplicity and versatility compared with a control implemented in the form of an electrical circuit .

The work presented aims to make a comparison between the control of a Buck converter, realized in the form of an electrical circuit and the programmed control managed by a programmable circuit. The control mode chosen is the so-called Pulse Skipping Modulation (PSM) mode. This command is often carried out in the form of a logic circuit controlled by a clock which will generate the pulses supplied to the converter switch. In the case of programmed control, the electrical circuit will be replaced by a program which operates on the same principle and must achieve the same result once it has been installed on a programmable circuit as a microcontroller type.

We will simulate the response of the converter submitted to the two types of control using SIMULINK / MATLAB, the objective being to make a comparison of the results obtained to highlight the advantages and disadvantages of each method.

II. BUCK CONVERTER AND PSM CONTROL

2.1 Buck Converter

The electrical scheme of the DC-DC converter used is shown in figure1:

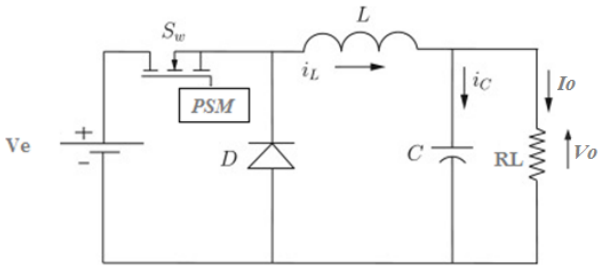

Fig. 1 Buck Converter

It is a Buck converter controlled by a PSM type impulse control device [1] [2].
The mode of operation adopted is that of Continuous Conduction Mode (CCM) [3], [4], [5].

The PSM regulator which will supply the pulses to the switch will act on the converter according to the result of comparison of the reference voltage (V_{ref}) and the output voltage (Vo) taken at the load R_L. It is introduced in the form of a MATLAB function which will apply to the switch (MOSFET) a clock signal H. The

clock frequency f_h and the duty cycle α remain fixed. When the load R_L output voltage (Vo) is lower than the reference voltage (Vref), the pulse train is sent to the switch, which will result in an increase in voltage across the load, that is the charging period of the capacitor. When Vo exceeds Vref the pulses are blocked and the opening of the switch causes discharge of the capacitor and consequently the decrease of the voltage across the load. When the output voltage (Vo) becomes lower than the reference voltage (Vref), the pulse train is applied again to the switch and the voltage Vo increases. Thus, when the steady state is established, the output voltage (Vo) will oscillate periodically around the reference voltage (Vref) with a ripple whose amplitude will be greater or less according to the value of the load resistor R_L.

2.2 Modelisation of PSM function

The operating principle of the PSM control is summarized in the flow chart of figure 2. Vref , Vo and H represent the input variables of the function and D the output variable [6].

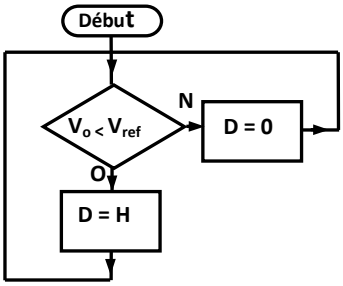

Fig. 2 PSM function flow chart

When the steady state is established after a transient phase, the clock signal with period T_h and duty cycle α will be applied to the MOSFET when Vo < Vref (charge period of the capacitor) and blocked in the opposite case (period of discharge). During the charging period, the MOSFET transistor will be on during the time αT_h and blocked during the time (1-α) T_h. If p is the number of cycles during which the clock signal is applied to the transistor and q the number of cycles during which the clock signal is absent as shown in figure 3, the effective switching frequency f_c of the MOSFET can be expressed by the relation relation [7], [8]:

$$f_c = \frac{p}{p+q} f_h \qquad (1) \qquad \left(f_h = \frac{1}{T_h} \right)$$

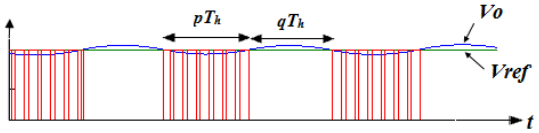

Fig. 3 Evolution of Vo and the PSM control signal in steady state

The modulation factor M is defined by the relation:

$$M = \frac{q}{p+q} = 1 - \frac{f_c}{f_h} \qquad (2) \qquad (\ 0 \le M \le 1\ )$$

It is shown that in the case of the continuous conduction mode (CCM), the mean value of the voltage Vo applied to the resistor R_L is given by:

$$V_o = (1 - M)\alpha V_e \qquad (3)$$

α is the duty cycle of the clock signal.

From the relation (6), the average current Io circulating througt R_L is deduced:

$$I_o = \frac{V_s}{R_L} = (1 - M)\alpha V_e / R_L \qquad (4)$$

It can be seen that only the modulation factor M can vary since the other parameters are constant. It is this variation which makes it possible to adjust the output voltage Vo to the reference voltage Vref.

It is also shown that to remain in the continuous conduction regime, the load resistor R_L must satisfy the condition:

$$R_L \le \frac{2Lf_h}{1-\alpha} \qquad (5)$$

For a given R_L load, the inductance L must satisfy the condition:

$$L \ge \frac{R_L}{2f_h}(1 - \alpha) \qquad (6)$$

In our simulation, we considered the charge R_L between 1Ω and 50Ω, α = 0.9 and f_h = 100kHz, Ve = 12V and

C = 100µF.
From the relation (9), the minimum value of L is deduced:

$$L_{min} = 25\mu H$$

In the simulation we took L = 200µH.

III. MATLAB SIMULATION OF PSM-CONTROLLED CONVERTER RESPONSE

3.1 Buck Converter under SIMSCAPE

The electrical circuit of the converter and the PSM control function are realized under MATLAB / SIMULINK in the form of two separate blocks, as shown in the figure 4:

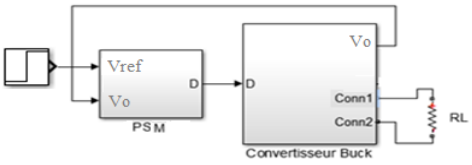

Fig. 4 Buck Converter and PSM control

The converter is realized under SIMSCAPE as shown in figure 5.

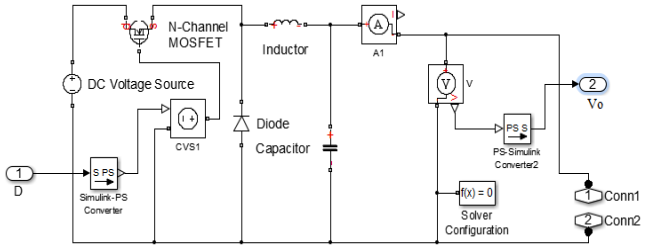

Fig.5 Buck Converter under SIMSCAPE

The PSM function which translates the flowchart of figure 2 is introduced in the form of a MATLAB embedded function D = f (Vref, Vo, H) whose inputs are the reference voltage (Vref), the output voltage (Vo) The clock signal (H) [6]. Output D will send the clock signal H to the converter as long as Vo < Vref and block it when Vo > Vref.

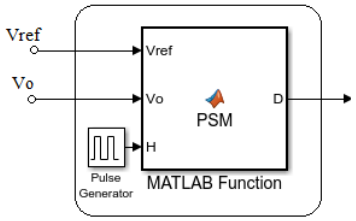

Fig. 6 PSM Function

The advantage of this software solution with respect to a hardware implantation is the simplification of the control circuit. A single microcontroller, containing the control program, is sufficient instead of a circuit comprising several logic gates and a clock circuit.

3.2 The hardware PSM control

The PSM function can also be performed using a logic circuit[9] as shown in the figure 7. When Vref-Vo > 0, the output of the comparator (Compare to Zero) passes to 1 (D = 1, D input of the D Latch), the output Q of the D Latch passes to 1 and the output of the AND gate will reproduce the clock signal. When Vref-Vo < 0, the input D of the D Latch passes to zero and subsequently the output Q, which will result in the blocking of the clock signal (output of the AND gate goes to zero).

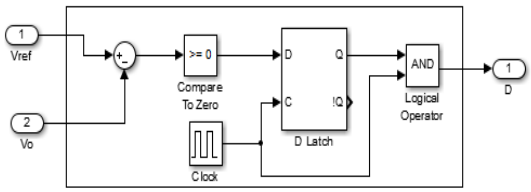

Fig.7 Control circuit

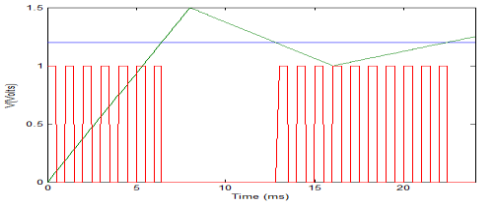

Fig.8 Evolution of PSM signal

The figure 8 Shows the evolution of the PSM signal. When Vo <Vref the clock signal is applied to the output of the circuit and when Vo > Vref the clock signal is blocked.

IV. SIMULATION OF THE CONVERTER RESPONSE

4.1 Form of the converter response to a constant Vref voltage

Figure 9 shows the evolution of the output voltage (Vo) and the control signal PSM. It should be noted that after a transient phase, the output voltage will tend towards the reference voltage with oscillations that are greater or less depending on the value of the load, this is the steady state.

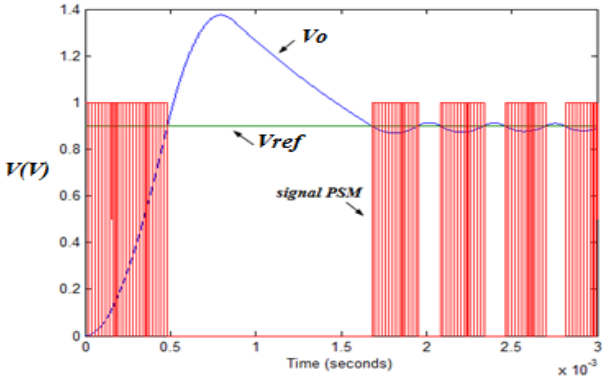

Fig. 9 Evolution of Vo and the PSM signal versus time

4.2 Comparison of the converter responses for the two types of control

Figure10 and figure11 Show the evolution of the output voltage Vo at the load R_L in response to a voltage step of amplitude 2V and for two different values of R_L.

The voltage step (Vref) appears after a delay of one millisecond. We have plotted on the same figure the shape of the output voltage Vo at the output for the two types of control.

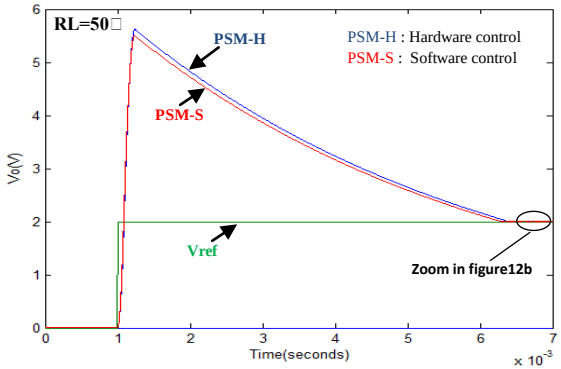

Fig.10 Evolution of the output voltage Vo with R_L = 50Ω and Vref = 2V

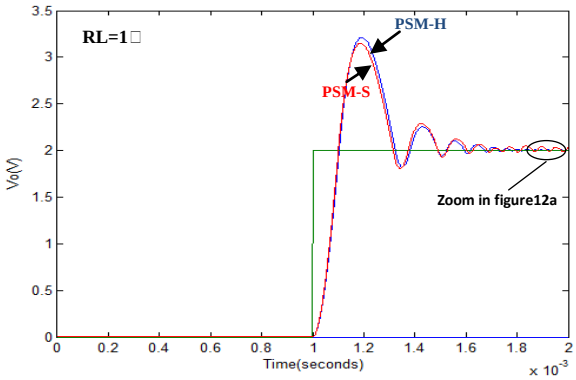

Fig.11 Evolution of the output voltage Vo with R_L = 1Ω and Vref = 2V

We notice that the curves are almost confounded and converge towards the reference voltage (Vref) more rapidly in the case where R_L = 1Ω. We note also the occurrence of oscillations for low R_L. This is explained by the decrease in the damping coefficient of the oscillating circuit constituting the converter when the value of the load resistance R_L decreases.

On the other hand, if we take a closer look at the steady state, we notice that the ripples are larger in the case of the programmed PSM control (ΔVo = 62mV) than in the other type of control (ΔVo = 7mV) as shown it in figure 12 (a).
The difference between the ripples from the two types of control decreases considerably for R_L = 50Ω as shown in (Figure12(b)). We observe ΔVo = 2mV in the case of programmed control against 0,8mV for the hardware type of control.

Fig.12 Oscillations of output voltage Vo in steady state at Vref = 2V

For a larger amplitude step (8V), it is also observed that the curves are almost coincident. We also note a lower oscillations for R_L = 1Ω (figure 14) compared to those of figure 11.
It should also be noted that the response time decreases considerably when the amplitude of the step increases, mostly for R_L = 50Ω as shown in figure 10 and figure 13.

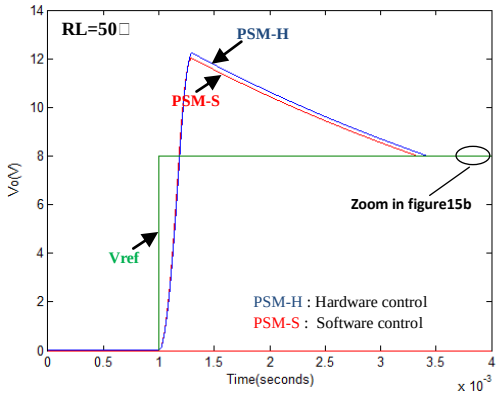

Fig.13 Evolution of the output voltage Vo with R_L = 50Ω and Vref = 8V

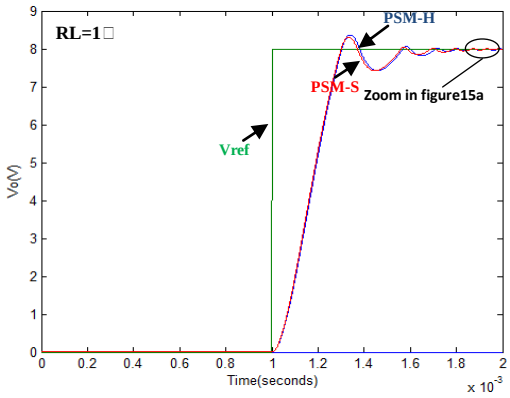

Fig.14 Evolution of the output voltage Vo with R_L = 1Ω and Vref = 8V

In the steady state, we note that as in the previous case, for R_L=1Ω, the ripples are larger in the case of the programmed PSM control (ΔVo = 38mV) than in the other type of control (ΔVo = 10mV) as shown it in figure 15 (a). The difference between the ripples from the two types of control decreases considerably for R_L = 50Ω. (Figure15(b)).

Fig.15 Oscillations of output voltage Vo in steady state at Vref = 8V

The ripple dimming for large R_L values is a characteristic of PSM mode control [9].

V. CONCLUSION

In this work, we studied and compared the behavior of a Buck converter controlled with Pulse Skipping Modulation mode (PSM). The control was carried out according to two different approaches. The first type of PSM control has been introduced in the form of a MATLAB embedded function whose output will provide a control signal which will be applied to the converter. The second type of control consists of a conventional electrical circuit made with logic gates and a clock which will supply the control signal to the converter. We compared the responses of the converter with the two types of control and found a strong similarity in both cases. The difference lies in the amplitude of the ripples of output voltage at steady state, especially for the lower values of the load resistance R_L. Ripples at steady state are more important under programmed control, this is the main defect of this type of control. The advantage of the programmed control is also its simplicity and flexibility, contrary to a conventional control. Thus, for example, the clock frequency, can be modified by programming without changing any components.

The other advantage is the economics of the components, so a simple microcontroller can replace all the electrical circuit of the PSM control realized with a clock circuit and several logic gates.

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