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SIMPLE AND FAST METHOD FOR DESIGNING A PROGRAMMABLE PSM MODE CONTROL OF A BUCK CONVERTER

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Abstract--The control of a DC-DC converter is usually done through an analog or digital circuit. In this work, we opted for a command controlled by a microcontroller. The PSM (Pulse Skipping Modulation) control is implemented by software instead of the conventional control based on an electrical circuit comprising logic gates and an external clock. The control program, implanted on a microcontroller dsPIC is translated directly from a diagram realized under SIMULINK using the tool MPLAB SIMULINK BLOCKSET. The use of the ISIS / Proteus simulator allowed us to compare the simulation results obtained from MATLAB and the practical electrical circuit of the converter and its simulated control under ISIS / Proteus.

Keywords-- Buck converter, PSM control, MPLAB SIMULINK Blockset, dsPIC, ISIS/Proteus.

I. INTRODUCTION

DC-DC 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 implanted in the form of analogue or digital circuits. Presently, 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 in comparison with a conventional control. The work presented falls within the scope of the programmed control. The control mode chosen is Pulse Skipping Modulation Mode (PSM). This command is carried out in the form of a logic circuit which is controlled by an external clock. In our case, this circuit will be replaced by a program which must achieve the same result and which will be implanted on a dsPIC microcontroller using a tool provided by the manufacturer of the microcontroller and integrated in MATLAB software. The practical circuit diagram representing the converter and the dsPIC containing the control program will be simulated under ISIS / Proteus and the results of this simulation will be compared with those obtained using SIMULIN/MATLAB.

II. BUCK CONVERTER AND PSM CONTROL

A. Buck Converter

The converter consists of a switch (MOSFET), a diode, an inductance coil L and a capacitor C with a resistive load as shown in figure-1.

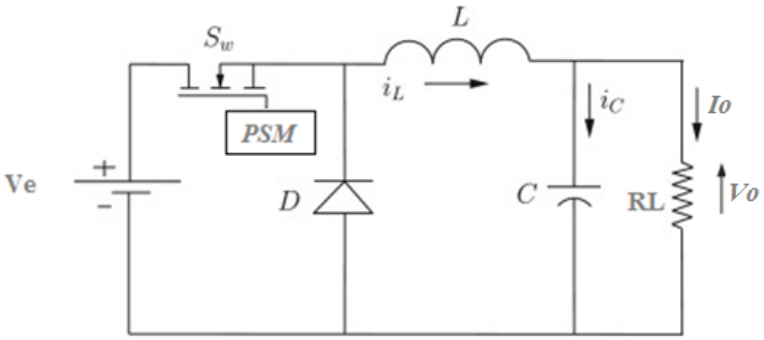

Figure-1. Buck Converter

The buck converter is controlled by a PSM type impulse control device [1],[2].
The adopted mode of operation is the continuous conduction mode (CCM) [3]-[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 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 and current 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 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 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.

B. Modeling the PSM Function

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

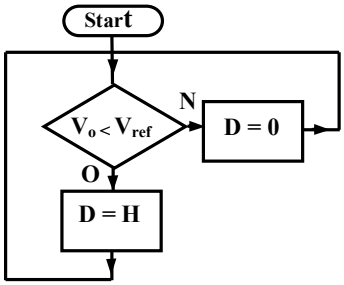

Figure-2. PSM function flow chart

When the steady state is established after a transient phase, the clock signal with period T_h (frequency f_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 figure3, the switching frequency f_c of the MOSFET can be expressed by the relation [7],[8]:

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

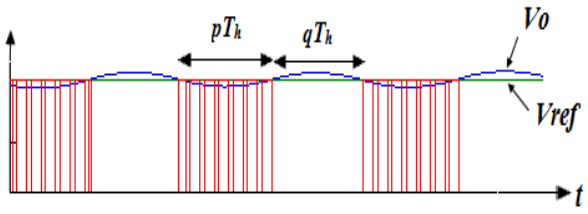

Figure-3. Evolution of Vo and the PSM control signal in steady state

The modulation factor M is defined by the relation:

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

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

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

α is the duty cycle of the clock signal.

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

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

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 established that to remain in the continuous conduction mode (CCM), the load resistor R_L must satisfy the condition:

$$R_L \leq \frac{2Lf_h}{1-\alpha} \quad (5)$$

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

$$L \geq \frac{R_L}{2f_h}(1-\alpha) \quad (6)$$

In our simulation, we considered the load R_L varies between 10 Ω and 100Ω, α = 0.9 and f_h = 100kHz, Ve = 12V and C = 100µF.

From the relation (6), the minimum value of L is deduced:

$$L_{min} = 50\mu H$$

In the simulation we chose L = 200µH.

III. MATLAB SIMULATION OF PSM-CONTROLLED CONVERTER

A. Buck Converter unde 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:

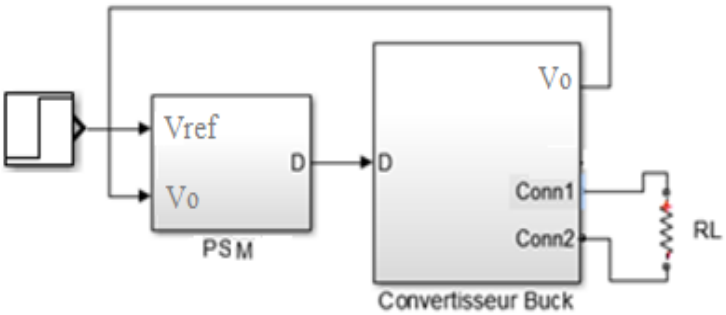

Figure-4. PSM Buck converter and PSM control

The converter is realized under SIMSCAPE as shown in figure-5. The R_{DON} resistance of the MOSFET is adjusted at 70mΩ. This value corresponds to the value of R_{DON} of the MOSFET RF470 given by the manufacturer and used in the simulation under ISIS/Proteus.

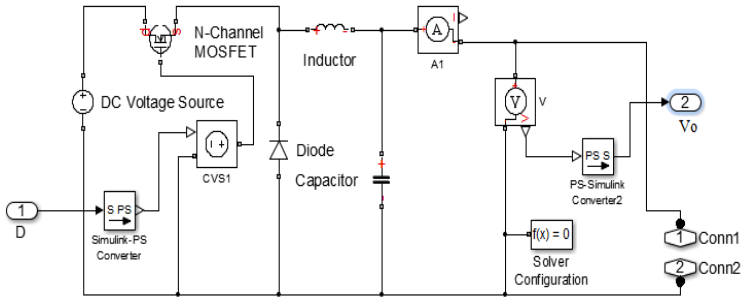

Figure-5. Buck converter under SIMSCAPE

A. The PSM control

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

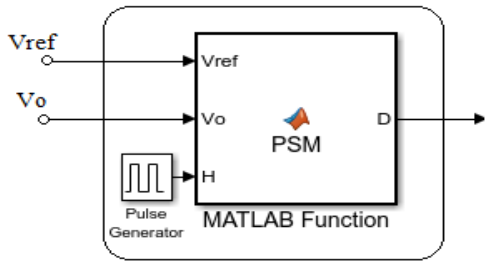

Figure-6. PSM Function

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 [9].

B. Converter response simulation

Figure-7 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.

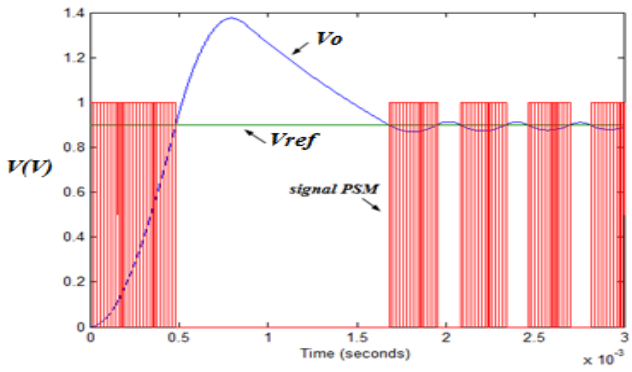

Figure-7. Evolution of Vo and the PSM signal versus time

The simulation also shows that the response time of the system (evolution of the output voltage Vo) is influenced by the value of the load as seen in figure-8.

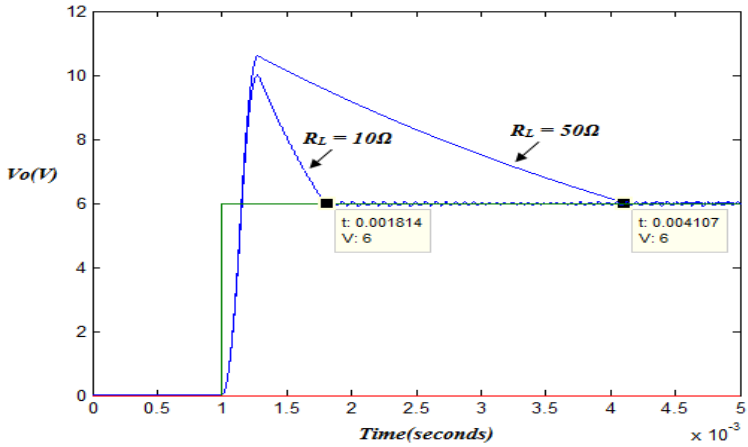

Figure-8. Output voltage Vo for two values of R_L

IV. IMPLEMENTATION OF THE CONTROL PROGRAM IN A DSPIC33 AND SIMULATION UNDER ISIS

A. Implementation of the control under MPLAB SIMULINK Blockset

The control part will be managed by a dsPIC33 according to the diagram in figure-9.
The control in PSM mode will be implemented in a microcontroller dsPIC33 (16 bits) of the Microchip family whose external clock frequency can rise up to 80MHz. The voltages Vo and Vref are applied to two inputs of the analog-to-digital converter integrated in the microcontroller and the output signal PSM is sent to a pin configured at the output as indicated in figure 10 and will be applied subsequently to the gate of the MOSFET through a driver [10], [11].

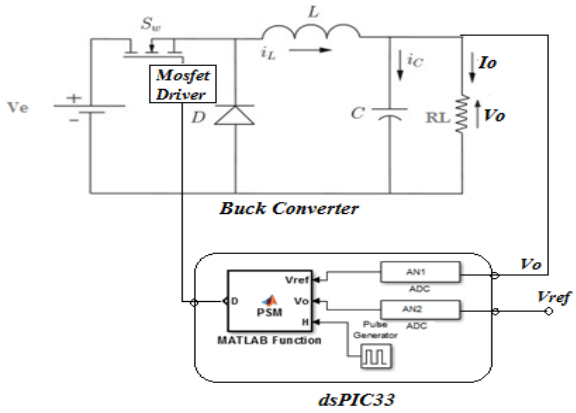

Figure-9. Buck converter and control circuit

The implementation of the PSM function is performed under version 3.39 of MPLAB Blockset for SIMULINK installed in the SIMULINK tool of MATLAB2016b software used in this study.

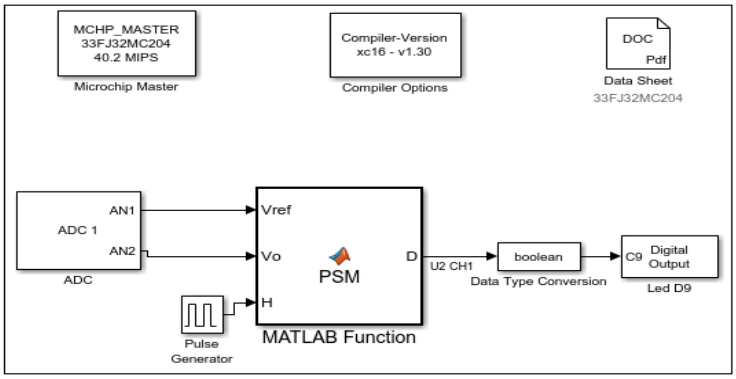

Figure-10. PSM function under Mplab Simulink Blockset

In our simulation, we used the dsPIC33FJ32MC204. This microcontroller belongs to the microchip dsPIC family, performing very well with computing power which can reach 70 MIPS (70 million instructions per second) and simulable under ISIS software. The compilation of the file under MPLABX using the xc16-v1.3 compiler will generate a source file in C language and the corresponding object file. It is the object file who will be charged in the program memoire of the dsPIC.

B. Complete circuit diagram under ISIS

The diagram of the circuit representing the converter and the control part (Figure-11) is carried out using the ISIS software.

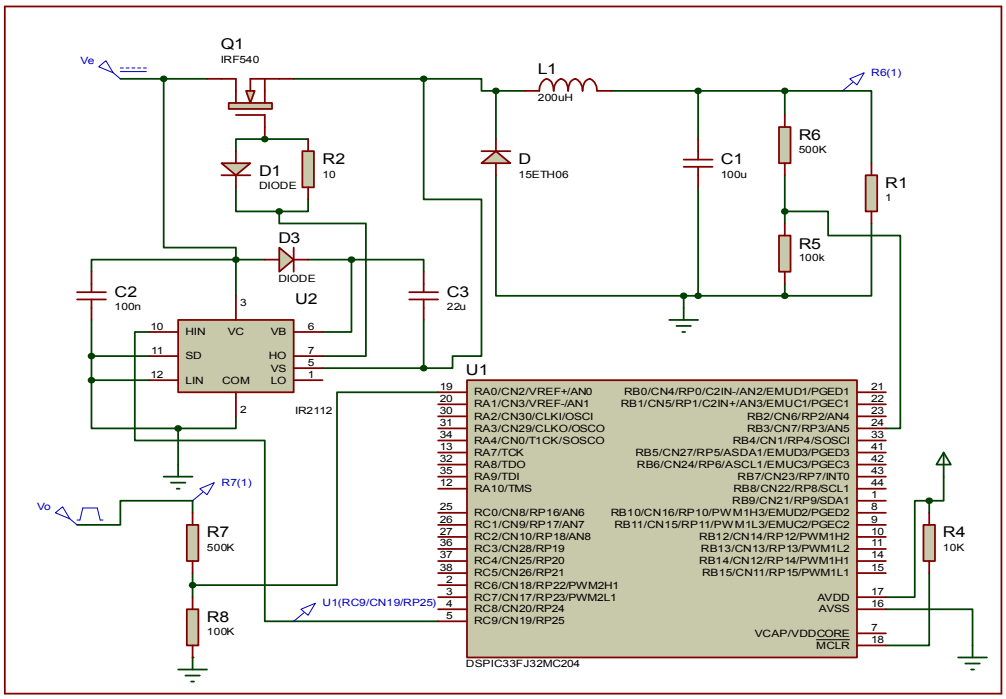

Figure-11. Converter and control circuit under ISIS

The control of the MOSFET RF470 used in this simulation will be provided by the driver IR2112.

The voltage dividers by means of high-value resistors serve to divide the reference voltage (Vref) and the output voltage (Vo) in the same proportions so that they do not exceed 5V, the maximum voltage accepted by the inputs of the analog-to-digital converter. The influence of these resistances is negligible for values of R_L not exceeding 100Ω.

C. Converter response simulation under ISIS

The ISIS simulation of the converter response to a voltage step of 12V and delayed by 1 millisecond is given in figure-12. We note the appearance of a transitional phase before the establishment of the steady state.

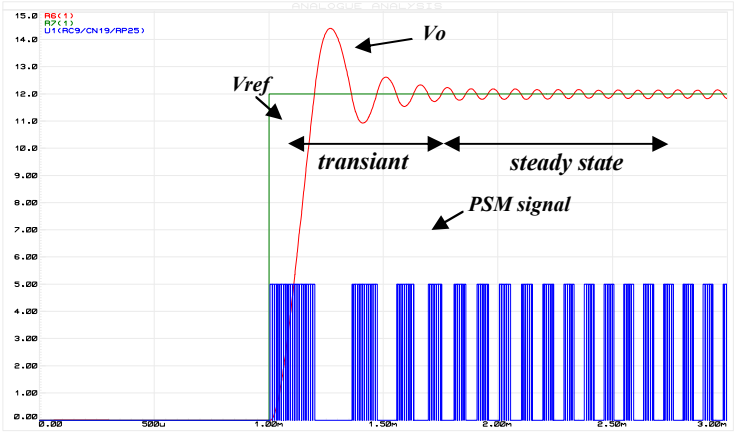

Figure-12. Output voltage Vo and PSM signal under ISIS

V. COMPARISON OF THE SIMULATION RESULTS OBTAINED BY ISIS AND MATLAB

A. Response to a voltage step for different load values

Figures-13a, 13b and 13c shows a good concordance between the simulation results under MATLAB and the simulation under ISIS with a slight offset between the curves and a larger peak of the simulated transient phase under MATLAB. This slight difference can be explained by the fact that the simulation was carried out under different simulators, with different assemblies, but the shape of the signal remains generally the same.

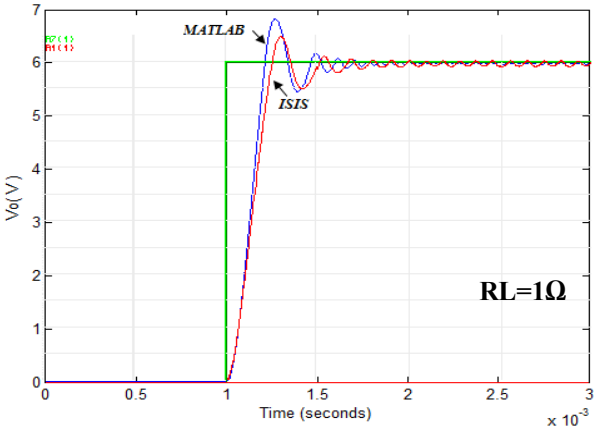

Figure-13a. Evolution of Vo for R_L = 1Ω

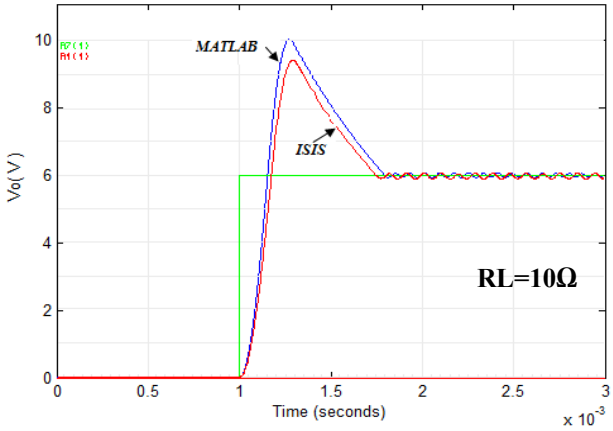

Figure-13b. Evolution of Vo for R_L = 10Ω

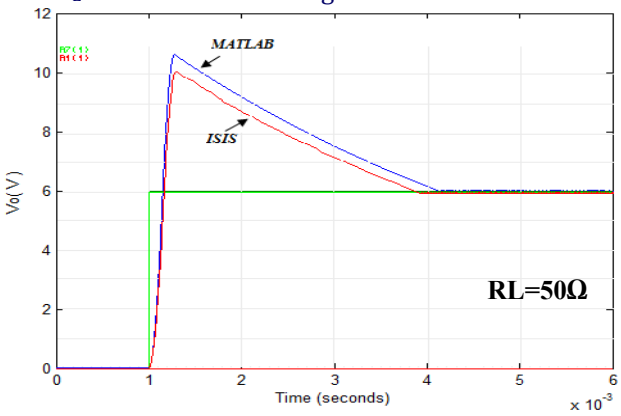

Figure-13c. Evolution of Vo for R_L = 50Ω

B. Converter response time

Figure-14 shows the response time of the converter for R_L values between 10Ω and 100Ω.

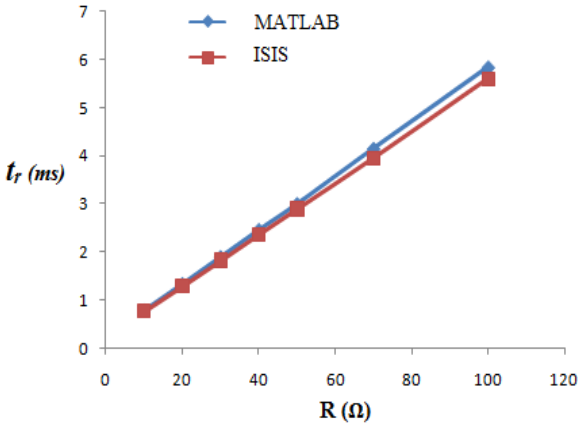

Figure-14. Evolution of the response time versus R_L under MATLAB and ISIS simulation

It is found that the curves are almost confounded for the low R_L values and diverge lightly for high R_L values. However, the offset between the two curves is very small.

C. Ripple ratios

Figure-15 shows the ripple ratios of the output voltage Vo (τ_{ond})computed with the two simulators.

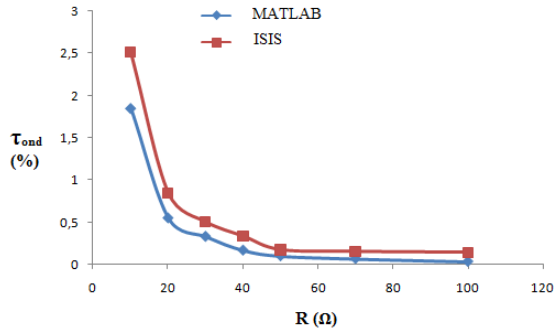

Figure-15. Evolution of the ripple ratio versus R_L under MATLAB and ISIS simulation

It is observed that the ripple of the output voltage Vo decreases when the value of R_L increases and the two curves tend to get confused. The decrease of the ripple for the large R_L values is a characteristic of the PSM mode control [12].

VI. CONCLUSION

In this steady, we studied the behaviour of a buck converter controlled in PSM mode. The PSM control was introduced as a MATLAB function instead of an electrical circuit consisting of logic gates and an external clock. The advantage of this programmed control is 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. In order to program the PSM function, we used the MPLAB Blockset for SIMULINK tool, a powerful tool that allows to directly translating the schema of a circuit realized under SIMULINK into a program C, which will be compiled and loaded on a dsPIC. The use of this tool greatly and efficiently simplifies the graphical realization under SIMULINK contrary to the conventional methods. Finally, we used the ISIS simulator to test and execute the compiled and loaded control program on a dsPIC33. The comparison of the "theoretical" results obtained under MATLAB and the "practical" results under ISIS showed a good agreement between the results obtained. The next step will naturally be the practical realization of the circuit and the comparison of the practical results with those presented in this study.

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