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Digital Simulation and Analysis of Sliding Mode Controller for DC-DC Converter using Simulink

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ABSTRACT

The switching converters convert one level of electrical voltage into another level by switching action. They are popular because of their smaller size and efficiency compared to the linear regulators. These are used extensively in personal computers, computer peripherals, and adapters of consumer electronic devices to provide dc voltages. The wide variety of circuit topology ranges from single transistor buck, boost and buck-boost converters to complex configurations comprising two or four devices and employing soft-switching or resonant techniques to control the switching losses. There are some different methods of classifying dc-dc converters. One of them depends on the isolation property of the primary and secondary portion. The isolation is usually made by a transformer, which has a primary portion at input side and a secondary at output side. Feedback of the control loop is made by another smaller transformer or optically by optocoupler. Therefore, output is electrically isolated from input. This type includes Fly-back dc-dc converters and PC power supply with an additional ac-dc bridge rectifier in front. The dc-dc buck converter is the simplest power converter circuit used for many power management and voltage regulator applications. Hence, in this paper the analysis and design of the control structure is done using simulink for the buck converter circuit.

Keywords-- Converter, switching losses, soft switching, dc-dc conversion, VMC, CMC, Sliding mode controller simulink

I. INTRODUCTION

The switched mode dc-dc converters are some of the simplest power electronic circuits which convert one level of electrical voltage into another level by switching action. These converters have received an increasing deal of interest in many areas. This is due to their wide applications like power supplies for personal computers, office equipments, appliance control, telecommunication equipments, DC motor drives, automotive, aircraft, etc. The analysis, control and stabilization of switching converters are the main factors that need to be considered. Many control methods are used for control of switch mode dc-dc converters and the simple and low cost controller structure is always in demand for most industrial and high performance applications [1]. Every control method has some advantages and drawbacks due to which that particular control method consider as a suitable control method under specific conditions, compared to other control methods [2]. The control method that gives the best performances under any conditions is always in demand. The dc-dc switching converters are the widely used circuits in electronics systems. They are usually used to obtain a stabilized output voltage from a given input DC voltage which is lower (buck) from that input voltage, or higher (boost) or generic (buck–boost) [3]. Most used technique to control switching power supplies is Pulse-width Modulation (PWM) [4]. The conventional PWM controlled power electronics circuits are modeled based on averaging technique and the system being controlled operates optimally only for a specific condition [4]-[6]. The linear controllers like P, PI, and PID do not offer a good large-signal transient (i.e. large-signal operating conditions) [4]-[7]. Therefore, research has been performed for investigating non-linear controllers. Advantages of hysteretic control approach include simplicity in design and do not require feedback loop compensation circuit [6] – [8]. The voltage-mode hysteretic controllers for synchronous buck converter used for many applications. The analysis and design of a hysteretic PWM controller with improved transient response have been proposed for buck converter [9]. The use of SM control techniques in variable structure systems (VSS) makes these systems robust to parameter variations and external disturbances [10]-[11]. Sliding mode control has a high degree of design flexibility and it is comparatively easy to implement. Switched mode dc-dc converters represent a particular class of the VSS, since there structure is periodically changed by the action of controlled switches and diodes [10]-[12]. So it is appropriate to use sliding mode controllers in dc-dc converters. It is known that the use of SM (nonlinear) controllers can maintain a good regulation for a wide operating range [13]. So, a lot of interest is developed in the use of SM controllers for dc-dc converters [14]. A detail discussion on the use of SM control for dc-dc power converters is given in [15].

II. DC-DC BUCK CONVERTER

The buck converter circuit converts a higher dc input voltage to lower dc output voltage. The basic buck dc-dc converter topology is shown in fig. 1.

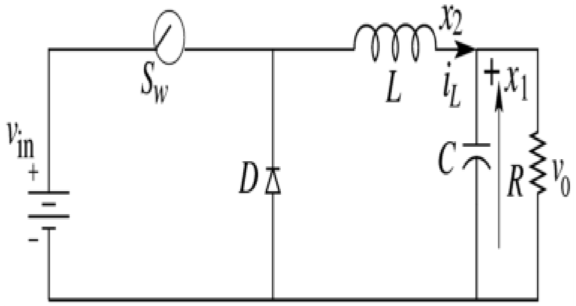

Fig. 1. Dc-dc buck converter topology

In the description of converter operation, it is assumed that all the components are ideal and also the converter operates in Continuous conduction mode (CCM). In CCM operation, the inductor current flows continuously over one switching period. The switch is either on or off according to the switching function *q* and this results in two circuit states. The operation of dc-dc converters can be classified by the continuity of inductor current flow. When the inductor current flow is continuous of charge and discharge during a switching period, it is called Continuous Conduction Mode (CCM) of operation. When the inductor current has an interval of time staying at zero with no charge and discharge then it is said to be working in Discontinuous Conduction Mode (DCM) operation.

III. CONTROL METHODS FOR DC-DC BUCK CONVERTER

Voltage-mode control and Current-mode control are two commonly used control schemes to regulate the output voltage of dc-dc converters. Both control schemes have been widely used in low-voltage low-power switch-mode dc-dc converters integrated circuit design in industry.

3.1 VOLTAGE-MODE CONTROLLED BUCK CONVERTER:

The voltage feedback arrangement is known as voltage-mode control when applied to dc-dc converters. Voltage-mode control (VMC) is widely used because it is easy to design and implement, and has good community to disturbances at the references input. VMC only contains single feedback loop from the output voltage. The voltage mode controlled buck converter circuit is shown in Fig. 3.

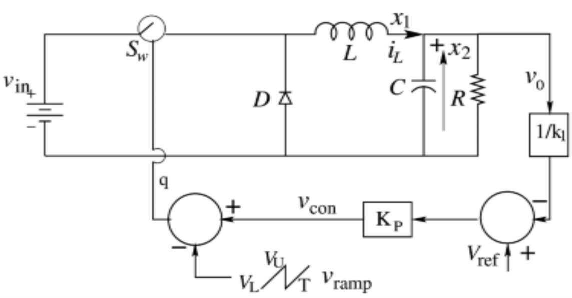

Fig. 2. Block diagram of voltage mode controller

The switch is controlled by analog PWM feedback logic. This is achieved by obtaining a control voltage V_{con}, as function of the output capacitor voltage V_c and reference signal V_{ref} in the form,

$$\text{Vcon} = k_p \left(v_{ref} - \frac{v_0}{k_1} \right) \qquad (1)$$

where, k_p is the gain of proportional controller and k_1 is the factor of reduction of the output voltage. An externally generated saw-tooth voltage defined as,

$$\text{Vramp (t)} = V_L + (V_U - V_L) F\left(\frac{t}{T_S} \right) \qquad (2)$$

Where T_s is the time period, V_U and V_L are upper and lower threshold voltages respectively.

3.2 CURRENT-MODE CONTROLLED BUCK CONVERTER

An added control scheme that is widely used for dc-dc converters is current mode control. Current-mode controlled dc-dc converters usually have two feedback loops: a current feedback loop and a voltage feedback loop. The inductor current is used as a feedback state.

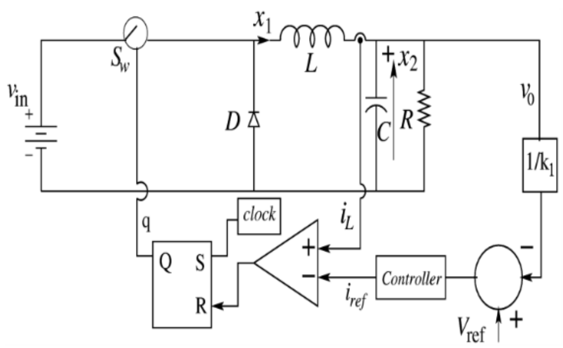

Fig. 3. Current-mode controlled dc-dc buck converter

A current mode controlled dc-dc buck converter circuit is shown in Fig..4. There are two types of current mode control strategies. In both, the switch is turned on at the beginning of every clock period. In peak current mode control, the inductor current is compared with a reference current signal with a compensation ramp, and the switch is turned off when the two become equal. The control voltage can be defined as,

$$\text{Vcon} = k_p \left(v_{ref} - \frac{v_0}{k_1} \right) \qquad (3)$$

IV. SLIDING MODE CONTROL FOR DC-DC BUCK CONVERTER

Buck Converter is a time variable and a nonlinear switch circuit which possesses variable structure features. Sliding mode control is well known for its good dynamic response and stability due to its insensitive for parameters change and easier in implementation, so this control technique is used extensively for the control of dc-dc power converters. A typical SM controller for switching power converters has two control modes: voltage mode and current mode. Here, voltage mode control is employed, i.e. output voltage V_o, is the parameter to be controlled. The schematic diagram of a SM voltage controlled buck converter is shown in Fig. 5.

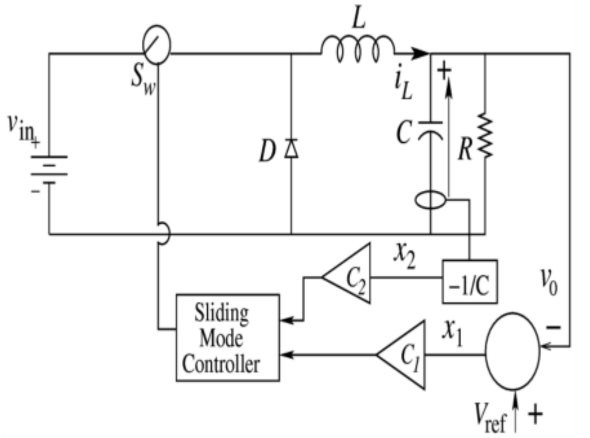

Fig. 4. Basic structure of an SMC buck converter system

The state space model describing the system can be derived as

$$\dot{x} = Ax + Bu + D \quad (4)$$

$$A = \begin{bmatrix} 0 & 1 \\ -\frac{1}{LC} & -\frac{1}{RC} \end{bmatrix}, B = \begin{bmatrix} 0 \\ -\frac{v_{in}}{LC} \end{bmatrix}, D = \begin{bmatrix} 0 \\ \frac{V_{ref}}{LC} \end{bmatrix} \quad (5)$$

For DCM, inductor current is zero before the next clock cycle. This creates constraints to the state variables.

V. DESIGN OF SM CONTROLLER

In Sliding mode controller, the controller employs a sliding surface to decide its input states to the system. For SM controller, the switching states *u* which corresponds the turning on and off of the converter switch is decided by sliding line. The sliding surface is described as a linear combination of the state variables. Thus the switching function is chosen as,

$$S = c_1 x_1 + c_2 x_2 = C^T X = 0 \quad (6)$$

This equation describes a sliding line in the phase plane passing through the origin, which represents the stable operating point for this converter. The sliding line acts as a boundary that splits the phase plane into two regions. Each of this region is specified with a switching state to direct the phase trajectory toward the sliding line. When the phase trajectory reaches and tracks the sliding line towards the origin, then the system is considered to be stable. The system dynamic in sliding mode can be modified as,

$$S = c_1 x_1 + c_2 \dot{x}_1 = 0 \quad (7)$$

Thus, if existence and reaching conditions of the sliding mode are satisfied, a stable system is obtained.

VI. SIMULATION RESULTS

The specifications and the circuit parameters for Simulations are as follows: input voltage V_{in} =20 V, Desired Output voltage V_o = 5 V, L =3 mH, C = 69 µF, R_{min} = 10 Ω, R_{max} = 15 Ω, Voltage reduction factor K_1 = 0.4, K_p = 2, the sliding parameters c_1 = 2 and c_2 = 0.001.

The dynamic performance of PWM based voltage mode controlled buck converter is compared with Sliding Mode controlled buck converter. The results from simulation for load change from 15 Ω to 10 Ω back to 15 Ω, step change in load, change in input voltage from 20V to 15V and back to 20V and inductor Current response for a change in input voltage from 20V to 15V and back to 20V of buck converter are given in Fig.6 to Fig.9.

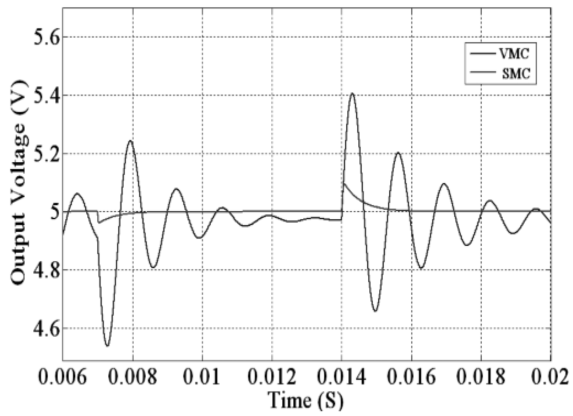

Fig. 5. Output voltage response due to a step change in load resistance

In Fig.6, the SM control Scheme takes 1.2ms settling time with an overshoot of 0.04volt as compared to 7ms and 0.5volt in case of the VMC. Hence, SM control has a smaller overshoot and zero steady state error than VMC. From Fig.7, we can see that the settling time is 0.04ms which is less compared to VMC. This shows poor large-signal transient response due to the oscillatory nature of the output voltage and the long settling time. From Fig.8-Fig.9, it is shown that the output of converter is not affected by the input voltage variation in case of SM control where as the performance of converter with VMC having a long settling time and larger steady state error.\

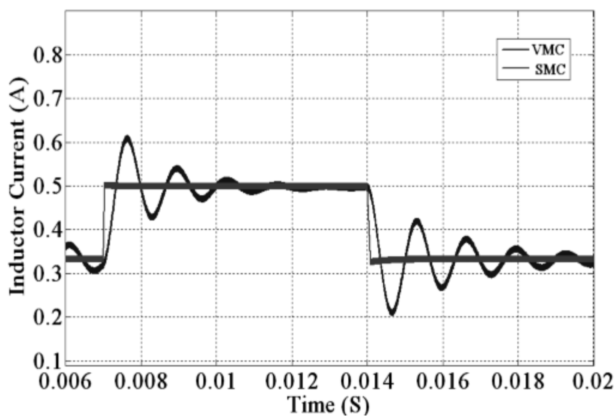

Fig. 6. Current response due to a step change in load resistance

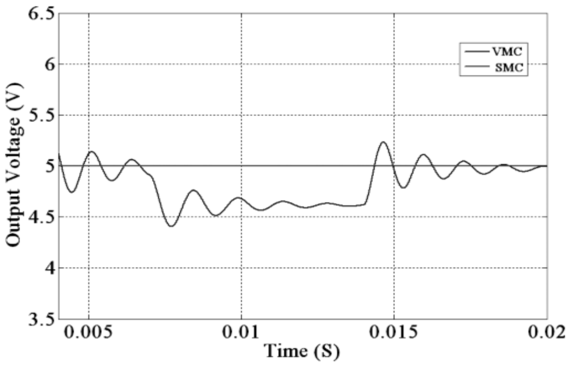

Fig. 7. Output Voltage response for a change in input voltage

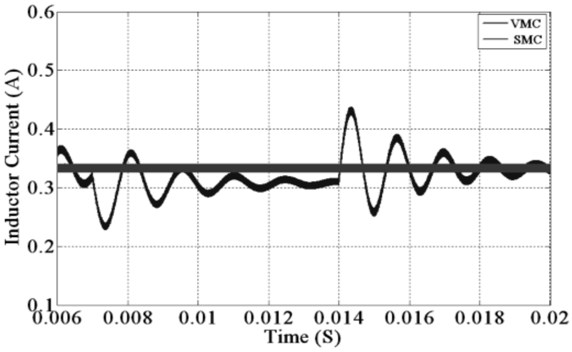

Fig.8. Inductor Current response for a change in input voltage

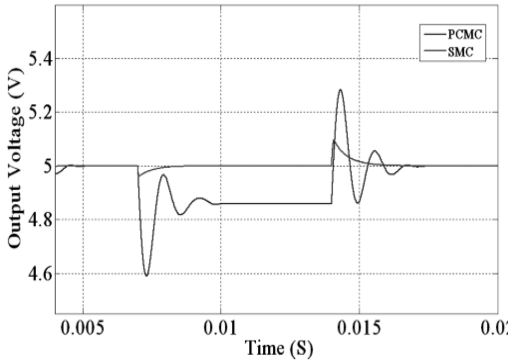

Fig. 9. Output Voltage response with step load transient

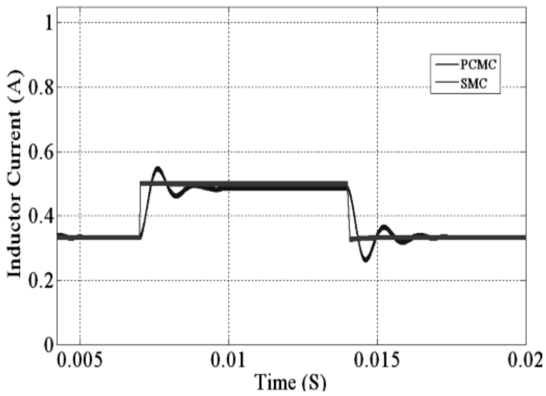

Fig. 10. Inductor Current response with step load transient

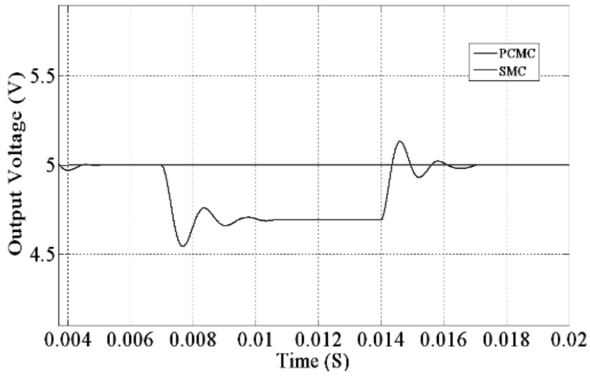

Fig. 11. Output Voltage response for a change in input voltage

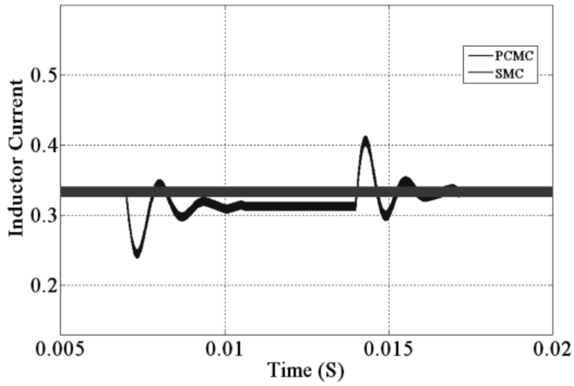

Fig. 12. Inductor Current response for a change in input voltage

The dynamic performance of Current-mode controlled buck converter is compared with SM controlled buck converter. The results from simulation for load change from 15 Ω to 10 Ω back to 15 Ω, step change in load, change in input voltage from 20V to 15V and back to 20V, and inductor Current response for a change in input voltage from 20V to 15V and back to 20V of buck converter are given in Fig.10 to Fig.13. It is seen that the transient response corresponding to SM controller is faster and has smaller overshoot when compared to the transient responses in CMC. The CMC is usually faster than VMC because of its additional inner current control loop and compensation technique used for PCMC is lesser complex than VMC. Also the transient response of CMC is faster than VMC. But, when the CMC method is compared with the SM controller, again SM control method is proved to be better solution for its robustness to line and load variations.

VII. CONCLUSION

The overview of different control methods for dc-dc buck converter is discussed and also the simulation results are presented. The performance of converters for change in load, change in voltage and transients are presented. The SM control method shows better dynamics for changes in input voltage and load compared to the PWM voltage-mode and current-mode control methods. It can be seen that the SM control method can well control the output voltage even in large range of load and line dissimilarity.

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