Practical Implementation of Sliding Mode Control for Boost Converter

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***Abstract*—The sliding mode control (SMC) represents a powerful tool to enhance performances of power converters. This control technique has a less circuit complexity unlike other standard current-mode controllers. It also provides extreme robustness and fast response against supply, load and circuit parameter variations, even for higher-order converters. Limited numbers of research publications are available with hardware implementation of SMC in switching power converters. Most of the people have discussed this control using a buck converter having a perfect variable structure. This paper presents a simulation study of SMC applied to a boost converter (Non minimum phase system) using a new model developed by the authors. MATLAB/SIMULINK is used for simulation studies. Simulation results are practically verified by implementing controller on a prototype board.**

***Keywords*— Sliding Mode Control (SMC), Variable structure systems (VSS), Pulse width modulation (PWM), Chattering, DC-DC Converter, Continues conduction mode (CCM))**

I. Introduction

Switched mode dc-dc converters are nonlinear and time varying systems. Their control design is normally done using small signal analysis around an operating point, so that one can apply linear control system theory. This approach is normally followed in the case of PWM converters. Alternative approach is to use of SMC concept, which is developed using Variable Structure Systems theory [3, 4]. In this method control state variables are forced in such a way to allow the system to stay on a selected surface called sliding surface. Principle of SMC is discussed in [4,5]. This results in a robust control of converter against line and load disturbances and also it leads to parametric insensitive control [3, 4, 5]. Only a few practical implementation of such control is reported in literature [6, 7]. Most of the people have discussed this control using a buck converter having a perfect variable structure, so that sliding mode control implementation is straightforward. Also, selection of sliding surface becomes simple if the converter is represented in state variable canonical form with voltage error and its derivative as state variables [4]. It is not the same in a boost converter. In this work simulation has been done using a model developed by the authors, reported in [2] .Cascaded current mode control is being used to implement the SMC. It consists of two loops. Outer loop consists of PI based control and inner loop. has SMC. Hardware implementation is done using cost effective high speed operational amplifiers

II. Sliding Mode Control Of Boost Converter

A. Mathematical Model Of Boost Converter

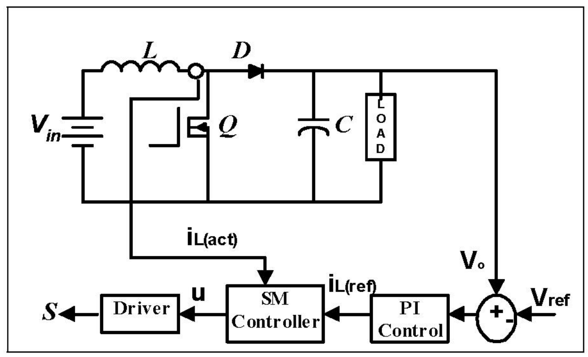

Fig.1. Scheme for SMC based boost converter

The state equations for a boost converter [1] during ON state can be written as

$$\begin{cases} \dfrac{di_L}{dt} = \dfrac{1}{L}(V_{in}) \\ \dfrac{dv_o}{dt} = \dfrac{1}{C}(-\dfrac{v_o}{R}) \end{cases}, \quad 0 < t < dT, \quad Q:ON \tag{1}$$

And when the switch is OFF

$$\begin{cases} \dfrac{di_L}{dt} = \dfrac{1}{L}(V_{in} - v_o) \\ \dfrac{dv_o}{dt} = \dfrac{1}{C}(i_L - \dfrac{v_o}{R}) \end{cases}, \quad dT < t < T, \quad Q:OFF \tag{2}$$

Using above state equations a matlab/simulink based model is developed in [2] in order to study the closed loop behavior of the converter using SMC principle. The model is a flexible masked subsystem in which user has a provision to enter the

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values of circuit parameters on a GUI window, so as to ensure that boost converter works in continuous conduction mode (CCM)[8]. Provisions have been made in the model itself to study the converter behavior during step change of line voltage and load current.

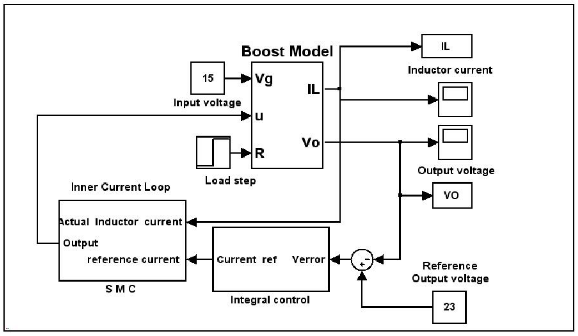

Fig.2. Simulink block diagram of SMC based boost converter

B. *Sliding Mode Controller*

For boost and buck-boost dc-dc converters the derivative of the output voltage turns out to be a discontinuous variable and we cannot express the system in canonical form [4]. With output voltage error as sliding surface, inducing sliding motions in a boost converter results in an unstable sliding regime [7]. For boost and buck boost converters the application of sliding mode control for output voltage regulation is not straightforward [5]. Using inductor current control all three topologies of converters are of reduced order and are equally amenable to application of sliding mode control [5]. The sliding surface is zero dimensional and reduces to a sliding point [5]. A cascaded loop structure is used to study the SMC of a boost converter [3].

The switching function 'S' (sliding plane) for the inner current loop is considered as

$$S = i_{L(act)} - i_{L(ref)} \tag{3}$$

$i_{L(act)}$ is the actual inductor current in amperes and $i_{L(ref)}$ is desired inductor current given by $\frac{V_d^2}{R*E}$, this is being obtained from the outer voltage loop.

Where, V_d - desired output voltage, R- Load resistance, E- Input supply voltage.

In order $i_{L(act)}$ to track $i_{L(ref)}$, Control input 'u' can be derived as [1]

$$u = 0.5*(1 - sign(S)) \tag{4}$$

According to equation (4) the control law is

$$u = \begin{cases} 1 \text{ for } S<0 \\ 0 \text{ for } S>0 \end{cases}$$

This control law is implemented using high speed operational amplifier LM311. It is used in non-inverting Schmitt trigger mode to implement a small hysterisis band around the sliding plane [6]. The circuit diagram is as shown in Fig. 3. There are two control loops. In the outer voltage loop a current reference is obtained using a PI controller. Proportional gain = 10 and Integral gain = 3. It is implemented using cost effective OPAMPS. Inner current loop is a sliding mode control implemented using non inverting Schmitt trigger LM 311. A suitable isolation is provided using 6N137 optoisolator. Switching devices used is IRF 540 MOSFET and MUR 860 diode. Micrel4420 is used as a driver.

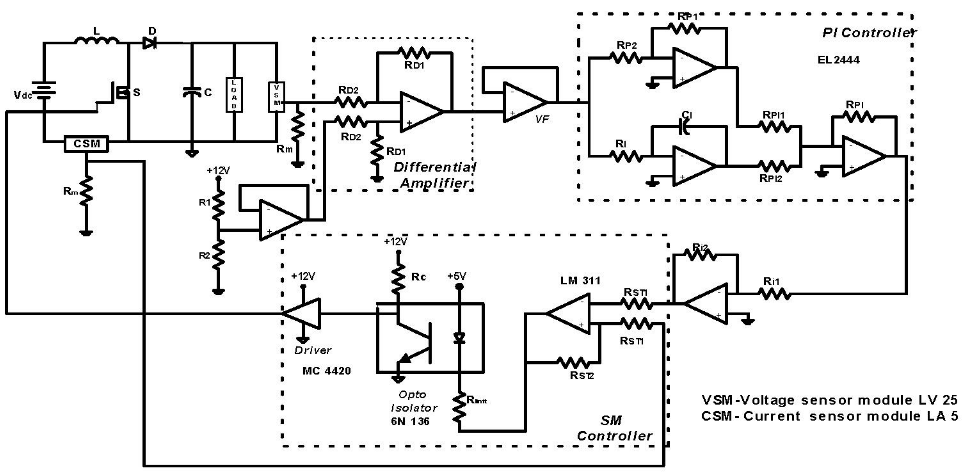

Fig. 3. Schematic diagram of SMC boost converter

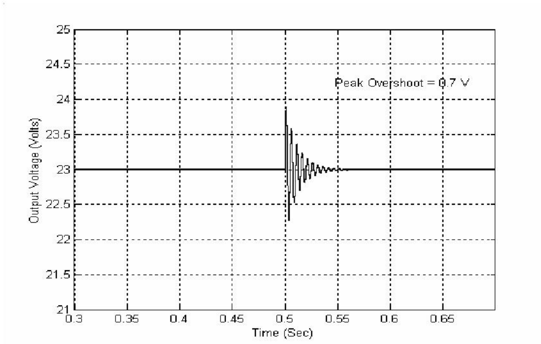

Fig.4.Step Response for a supply change from 10V -16V at t = 0.5sec.

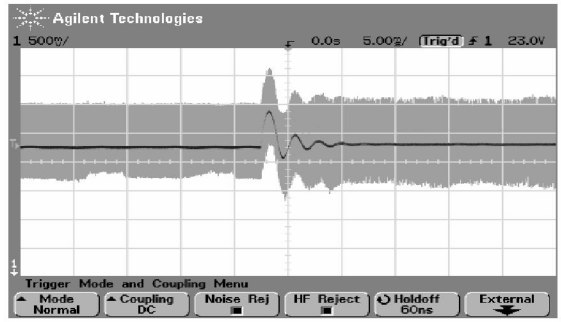

Fig.5.Step Response for a supply change from 10V - 16V at t = 0.5sec.

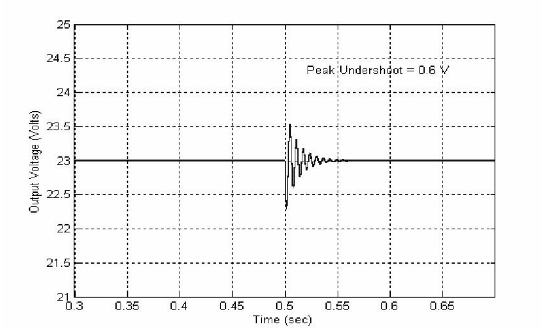

Fig.6.Step Response for a supply change from10V -16V at t = 0.5sec

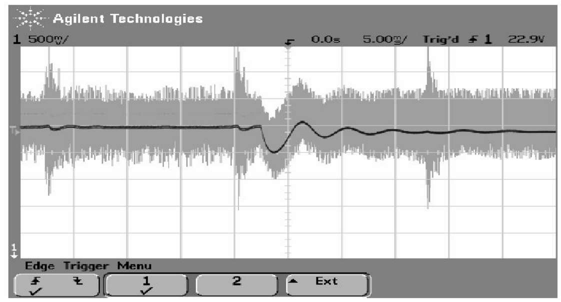

Fig.7. Step Response for a supply change from1 6V - 10V at t = 0 . 5 sec

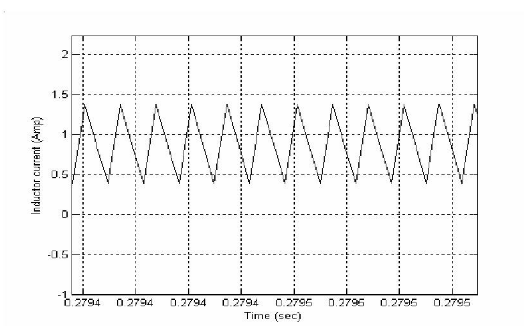

Fig.8. Steady state Inductor current for a Input voltage = 15V and R_L = 40Ω

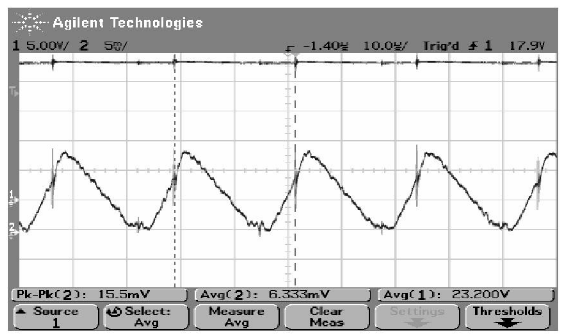

Fig.9. Steady state Inductor current and Output voltage for an Input supply voltage = 15V and R_L = 40Ω

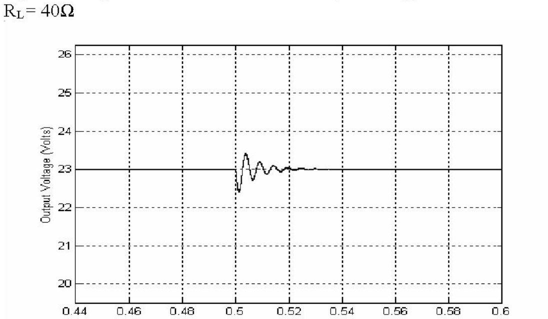

Fig.10.Output voltage for a Input voltage = 15V and R_L40Ω to 30Ω

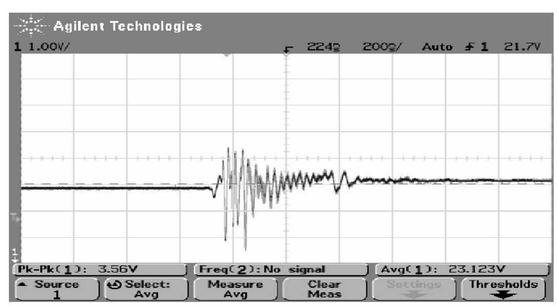

Fig.11.Output voltage for a Input voltage = 15V and R_L Changed from 40Ω to 30Ω

Converter parameters are listed in Table 1

TABLE 1. BOOST CIRCUIT PARAMETERS

Parameter	Symbol	Value chosen
Input voltage	V_{dc}	12 V to 20V
Output voltage	V_0	23V
Output Capacitor	C	220 μF
Input Inductor	L	70 μH
Load Resistance	R	30 Ω to 50 Ω

Fig. 12 Experimental setup

III. RESULTS AND DISCUSSIONS

A prototype of the converter of 20W is developed on a general purpose board with IRF540 MOSFET as power switch. Other major components are EL2444, a high slew rate operational amplifier from Intersil corp., USA. The switching frequency is around 28 kHz. Both steady state and dynamic condition waveforms of simulation and hardware results are given in Fig.4 to Fig. 11. Fig. 4 and 5 represents step input voltage change from 10 V to 16 V. A peak overshoot of 0.7 Vis observed. Fig. 6 and 7 represents a step input voltage change from 16 V to 10 V. A peak undershoot of 0.6 V is observed. In both the case, an average settling time is 7 ms. Fig 8 and 9 represents steady state inductor current and output voltage for a power output of 17 W. A steady state error of 20 mV (0.86%) is recorded. To study the dynamic behavior during load change, load resistance is varied from 40 Ω to 30 Ω (13 W to 17 W) and waveforms are as shown in Fig. 10 and 11.There was a drop of 0.2 V across the load.

IV. CONCLUSION

This paper presents realization of SMC based Boost converter by means of both hardware and software. In the software approach, author uses a novel modeling approach to verify the properties like robustness and parametric insensitivities. In the hardware approach, the circuit is realized using cost effective, high speed OpAmps such as LM311. Dynamic performance of the converter for both line input and load output variations are studied. Hardware results are in agreement to the simulation results. The time domain specification such as voltage peak overshoot at the output voltage is also calculated and is satisfactory. The usage of sensors is not a mandatory. It is also possible to realize the same using simple resistive transducers.

ACKNOWLEDGMENT

The authors gratefully acknowledge for support given by Intersil Corporation, USA. for supply of high speed Operational Amplifiers and power MOSFET drivers, also authors extend their acknowledgement to O. Sudhir Kumar, Ram Prasad Panda for their help during the course of implementation.

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