Design of a Soft Switching Technique and Sliding Mode Controller for Performance Enhancement in DC Buck Converters

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Abstract— This paper is about the use of non-linear Sliding Mode Controller (SMC) for DC-DC Buck converters to enhance the performance parameters of the converter such as rise time, settling time, peak time, delay time. The non-linear control method is then compared with the linear Proportional Integral (PI) controller and it is find that non-linear control strategy is better suited for fast response of the system. Also, a Soft switching technique using ZVS scheme is used at the converter input to minimize the switching losses and EMI.

Key words: Sliding Mode Controller, PI Controller, Soft Switching, Zero Voltage Switching (ZVS)

I. INTRODUCTION

A. SMPS

A switched-mode power supply, SMPS, or switcher is an electronic power supply that incorporates a switching regulator to convert electrical power efficiently. Like other power supplies, an SMPS transfers power from a DC or AC source to DC loads, such as a personal computer, while converting voltage and current characteristics. The switch mode DC-DC converters are some of the simplest circuit which converts power level of DC power effectively. These converters used for electronic devices are designed to regulate the output voltage against the changes of the input voltage and load current. It has wide application in modern computer, DC motor drive, power system, automotive, aircrafts etc.

A DC-DC converter or chopper circuit is a static power electronic device which converts fixed DC voltage/ power to variable DC output voltage/power directly. It is in fact a high speed switch which connects and disconnects the load from the source at a high speed, resulting in chopped or variable DC voltage at output. A chopper is a DC equivalent of an AC transformer; as they can step up or down the output DC voltage. The one step conversion in choppers makes them more efficient, fast with smooth control.

B. Soft Switching Techniques

Power switches used in DC converters have to cut off the load current within the turn off and turn on times under the hard switching conditions. Hard switching refers to stressful switching behaviour of the power electronic devices. However, stresses on devices are heavily influenced by the switching frequencies accompanied by their switching losses. The switching loss is proportional to the switching frequency, thus limiting the maximum switching frequency of the power converters. It is obvious that switching-aid-networks do not mitigate the dissipation issues to a great extent. Soft switching techniques use resonant techniques to switch ON and OFF by either forcing current (ZCS) or voltage (ZVS) or both of them to zero. Thus reducing the switching loss in converter circuits.

C. Controllers

There are mainly two methods of controlling the DC-DC converters. One is the traditional method that is linear control. With the help of linear control satisfactory result can be obtain until a certain limit. Due to huge load variation and source voltage variation linear control may not give satisfactory result. PI controller is a very popular linear controller. The other method is non-linear control technique. The dc-dc converters, which are non-linear and time variant system, and do not lend themselves to the application of linear control theory, can be controlled by means of sliding mode (SM) control, which is derived from the variable structure control system theory (VSCS) [4]. The more advance Control method is Hysteresis control method. It gives more stable output with a very minimal settling time. Both have wide application in power converter section. The control method that gives the best performances under any conditions is always in demand.

II. PRINCIPLE OF DC CHOPPER CIRCUIT

Chopper is a high speed semiconductor device, connecting and disconnecting load to the source at a high speed. The operation of the converter is explained below:

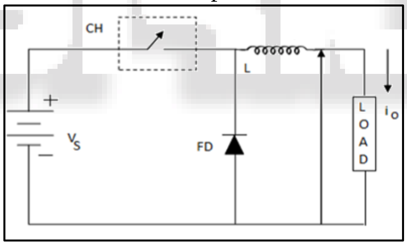

Fig. 1: DC chopper circuit

A chopped output DC voltage is obtained from a fixed DC voltage Vs at the input.

1) The CH represents a chopper which can be turned on and off as desired.
2) During T_{ON} the chopper is on and load voltage V_o is equal to Vs.
3) During T_{OFF} the chopper is off the chopper is off and the load current will be flowing though the freewheeling diode FD. The load terminals are short circuited by FD and the load voltage is therefore zero during T_{OFF}.
4) Thus, a chopped DC voltage is produced at the load terminals.
5) During the on period load current I_O rises, but during the off period of chopper the load current decays.

Buck, Boost, Buck Boost are the basic types of DC chopper circuits. The converter used in this research work is a buck converter or step down chopper which gives low DC voltage at the output with respect to high DC at the input.

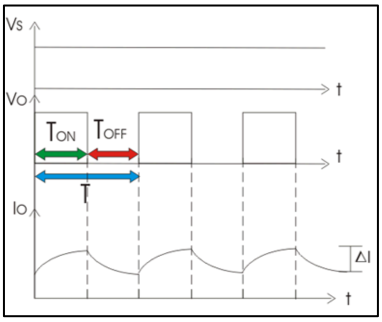

Fig. 2: Output voltage (V_o) and current (Io) waveforms for a chopper circuit with constant input voltage (Vs)

Here,

V_O= average load voltage

$V_O = T_{ON} Vs / (T_{OFF} + T_{ON})$ (2.1)

$V_O = T_{ON} Vs / T = KVs$ (2.2)

$V_O = f\, Ton\, Vs$ (2.3)

$f = 1 / T$ = Chopping Frequency (2.4)

$T = T_{ON} + T_{OFF}$ = Chopping Period (2.5)

$K = T_{ON} / T$ = Duty Cycle (D) (2.6)

Thus the output voltage V_O can be varied by varying the duty cycle D.

III. Methodology Used

- Design of a soft switching circuit at the input to minimize switching loss by using ZVS strategy.
- Further, designing of a digital non-linear controller i.e. Sliding Mode Controller in feedback loop of DC-DC Converter for fast response of converter circuit.
- Finally, the comparison of the sliding mode controller with the linear PI controller.

IV. Simulation of Proposed Technique

In this paper, closed loop SMC control of DC to DC buck Converter is simulated in MATLAB/Simulink environment [1]. The simulation is done for both, PI controller as well as the Sliding Mode Controller and their performances are compared. Fig. 3 shows the simulation diagram for DC to DC converter using Sliding Mode Controller. The simulation using PI controller also is performed in order to observe the responses of both controllers and compare them. The resonant components used for soft switching of the buck converter are capacitor C2, inductor L2 and diode D2[3]. The pulse from the SMC controller is being given at the switch of buck converter. It is the controlling signal for the converter circuit and modifies all the transient parameters of the converter.

A. *Sliding Mode Controller*

SMC is a digital non-linear controller especially used for controlling non-linear circuits. It is derived from the variable structure control theory (VSCS) and is well suited for non-linear systems [2]. Sliding mode control alters the dynamics of a nonlinear system by application of a discontinuous control signal that forces the system to "slide" along a cross-section of the system's normal behavior.

B. *Parameters for Buck Converter*

The various parameters while the designing of buck converter in Simulink are given in Table 1.

Inductor	1e-3 H
Capacitor	100e-6 F
DC input voltage	80 V
DC output voltage	40 V

Table 1: Designing parameters

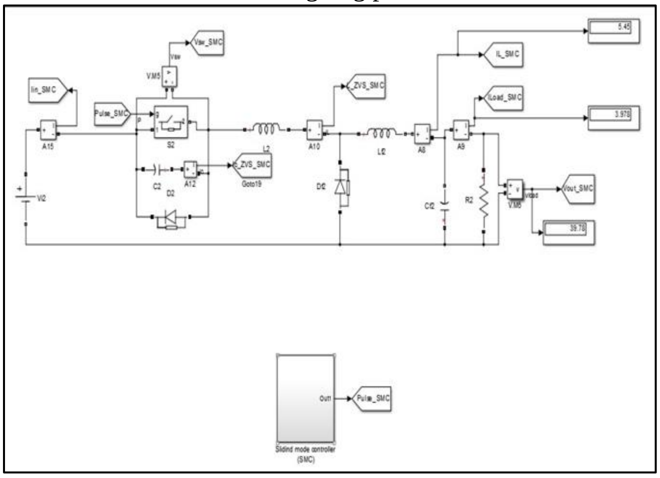

Fig. 3: Simulation diagram for ZVS DC to DC buck converter using Sliding Mode Controller

V. Simulation Result in Simulink

The simulation result shows the output voltage with time for PI and SMC controlled ZVS buck converter, when a step change of 20V is made in the reference voltage i.e. when Vreference goes to 40V from 20V. The vertical axis represents the output voltage in Volts. The horizontal axis represent Time in seconds.The red colour in the simulation graph represents SMC controlled buck converter and the pink colour represents PI controlled buck converter. Table 2 represents the transient response parameters for the converter circuit with PI and Sliding mode controller.

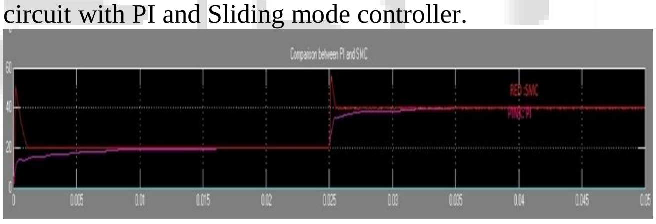

Fig. 4: Simulation result showing comparison between PI and SMC controlled Buck converter

Parameter	PI Controller	SMC Controller
Rise time	0.0024secs	0.0001secs
Settling time	0.01secs	0.00051secs
Peak time	0.0489secs	0.0252secs
Delay time	0.0254secs	0.0251secs

Table 2: Characteristics

From Table 2 it is clear that we get better results for SMC controlled buck converters. As the system reaches its steady state earlier as compared to PI controlled converter, making the system fast and robust.

VI. Conclusion

Sliding Mode Controller for controlling transient response of a soft switched (ZVS) DC Buck converter has been modeled and simulated on MATLAB/SIMULINK in this research work. The PI controller has also been implemented for the same conditions. The result is shown as a comparison between PI controller and Sliding Mode Controller which proves that under similar parameters the SMC control has better results in terms of rise time, settling time, peak time, and delay time. Thus, for step down converter circuits which require fast transient response in their operation, non-linear SMC controller can be used. The system with SMC control gives stability and robustness irrespective of system uncertainties. It is also easy to implement as compared to other non-linear controllers. These properties make SM control highly suitable for applications in nonlinear systems. It is pretty well suited in industrial applications, e.g., electrical drivers, automotive control, furnace control, etc.

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