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Characteristics Verification of DC- DC Buck Converter Using Nonlinear Controller with the PI Controllers

Arti Sachin Bindu
Assistant Professor, Department of Electrical Engineering
Nutan Maharashtra Institute of Engineering and Technology. Talegaon, Pune, Maharashtra, India
artibindu1978@gmail.com

Abstract: *In this project buck converter is simulated with variety of existing linear controllers like PI and PID. After analyzing the performance of buck converter from many papers it was found that nonlinear control sliding mode control can be used with buck converter. The performance of buck converter has been studied and is undertaken for their theoretical verification, graphical representation and Matlab simulation. From the linear controller PI, non linear controller sliding mode control (SMC) is taken as control method. As the concepts of linear controllers PI and PID are known to us, the concept of sliding mode control (SMC) is explained in detailed.*

Keywords: SMC (Sliding Mode Control), PI and PID Control

I. Introduction

DC –DC converter convert DC voltage signal from high level to low level signal or it can be vise versa depending on the type of converter used in system. Buck converter is one of the most important components of circuit it converts voltage signal from high DC signal to low voltage. In buck converter, a high speed switching devices are placed and the better efficiency of power conversion with the steady state can be achieved. In this project work performance of buck converter is analyzed. The circuit may consist of nonlinearity like delay, hysteresis etc. and because of this output voltage is not constant. To settle the output voltage within minimum settling time and less overshoot different types of controllers are considered such as linear controller PI, PID and in nonlinear controllers SMC (sliding mode controller).

This project deals with comparison of performance of DC-DC buck converter using controllers PI,SMC. The performance of buck converter has been analyzed in many papers amongst them papers [1][2] have been studied and are undertaken for their theoretical verification, graphical representation and Matlab simulation.

Buck converter is consider with different types of controller and for each type of controller rise time, settling time and peak overshoot , loading effects etc. are studied, and its performance is analyzed. The objectives of this project are listed below,

- To study the concept of buck converter.
- Literature survey for buck converter with PI , PID and SMC .
- To study the concepts of non linear controller sliding mode control,
- To simulate buck converter with different types of controllers for finding performance of circuit. This simulation will be carried out on matlab platform with Simulink as it user interface
- To compare performance response of PI,

II. Basics of Sliding Mode Control (SMC)

A Variable structure system (VSS) is theory which is applied to system to study the behaviour of system during the transient, according to a preset structure control law, to achieve the control objectives. The instant of time, at which the control action of changing the structure occurs, are not determined by a fixed program, but in accordance with the current state of the system. This property distinguishes variable structure systems (VSS) from programmed controllers.

From this point of view, switch-mode power supplies represent a particular class of the VSS, since their structure is periodically changed by the action of controlled switches. The SMC for VSS offers an alternative way to implement a control action, which exploits the inherent variable structure nature of DC-DC converters

The VSS are represented through the phase plane description of the constituent substructures. The phase plane description is the description of the different types of phase trajectories encountered in second order systems. Phase trajectories described by using simple second order systems and its important features of sliding mode control are studied in this chapter. The concept of sliding control is defined by graphical visualization of phase trajectories. Axes are the states of systems. The phase plane is divided into number of substructure and then the overall phase trajectory is composed for each substructure.

Sliding mode was studied in conjunction with DC to DC converter. Nonlinearity, a system problem is considered with this. It is focused only on the hysteresis type of switching nonlinearities since it is most relevant to any electronic implementation of the switching device, including both analog and digital circuits and microprocessor code executions.

The chattering phenomenon is generally perceived as motion which oscillates about the sliding surface. There are two possible mechanisms which produce such a motion. First, in the absence of switching nonlinearities such as delays, hysteresis i.e., the switching device is switching ideally at high frequency. The presence of nonlinearities in series with the converter causes a small amplitude high frequency oscillation to appear in the neighborhood of the sliding surface.

2.1 Reaching Mode

The trajectory starting from anywhere in the phase plane in which the representative point moves to the switching line and reaches it is called reaching mode. In other words it is the time required to reach the error or rate of change of error to zero. The condition under which it occurs is called reaching condition.

2.2 Sliding Mode

In this mode trajectory asymptotically tends to the origin of phase plane. To produce the discontinuous control signal which forces the system state to repeatedly cross and that immediately re-cross the surface, called “sliding surface” until it finally slides along the surface. This kind of motion is referred as sliding motion or sliding mode. As illustrated in figure 3.3.

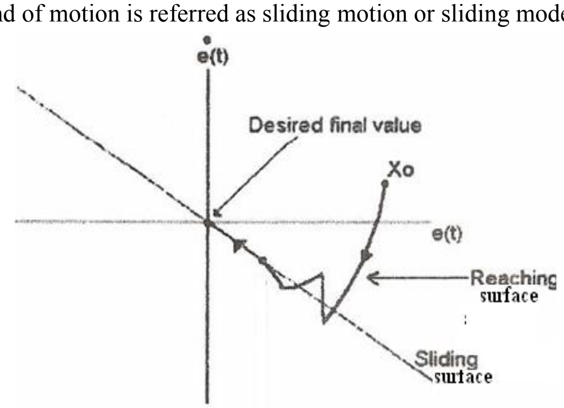

Figure: Modes in SMC**.**

The phase plane description is used widely to characterize second order systems. The axes of the phase plane are the system states. The instantaneous state of the system is represented on the phase plane by a Representative Point (RP) whose coordinates on the phase plane are the present states of the system. The study of the system involves the motion of the RP on the phase plane under different input and initial conditions. The evolution of the system states with respect to time on the phase plane, referred to as the phase trajectories or the state trajectories, represent the dynamic properties of the system.

III. Simulated Model of Buck Converter

Simulated model of buck converter by using Matlab are as shown in Figure. It consist of 24 V input DC supply, GTO (gate turn off thyristor) as switch, PWM (Pulse width modulation) generator for providing switching pluses to GTO. Inductor is of 69 µH[1] and capacitor is of 220µF[1], with load resistance of 13 Ω [1] .The desired output from this converter is 12 V DC.

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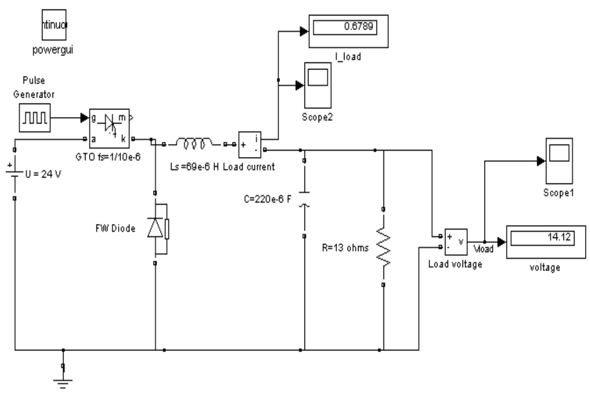

Figure: Buck converter in Matlab Simulink.

The circuit has settling time of 2 msec and output voltage is 14.12 V which is required to settle at 12 V. To compensate these transients present in buck converter different types of controllers can be used.

IV. Control Methods

Figure shows the block diagram with some methods that can be used to control DC-DC converters and the disturbances that have influence on the behavior of the converter and its stability. The feedback signal may be the output voltage, the inductor current, or both. The feedback control can be either analog or digital control. From these control methods PI, PID are linear control methods and SMC, SMC PID are the non- linear control methods. Comparison between linear and nonlinear control methods are given below.

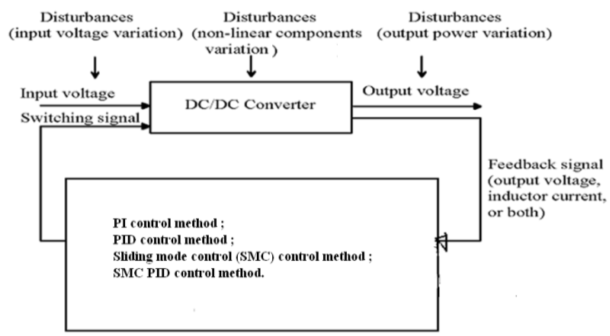

Figure: Types of controller.

4.1 PI Control Method

Settling time of PI compensated buck converter circuit is 11 msec initial overshoot for output voltage is 27 V and 43 A for inductor current. After settling time of 11 msec output voltage is at 12V and inductor current is at 1.738 A.

Load Voltage

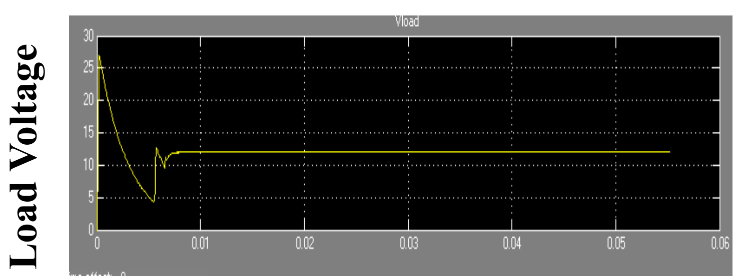

Figure: Load voltage of buck converter in Matlab/Simulink^{TM} model.

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Inductor Current

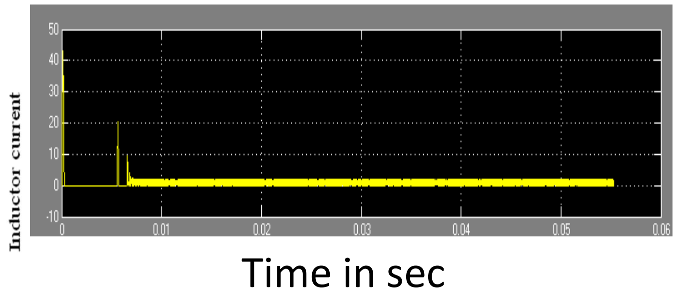

Figure: Inductor current from simulation.

4.2. Effect of Variation of Load Resistance on Buck Converter with PI Control

When buck converter is considered with PI control it has settling time of 11 msec and output voltage is at 12 V. When the circuit was tested under the load variation from 0 (open circuit) to short circuit, it was found that as load resistance increases load current decreases.

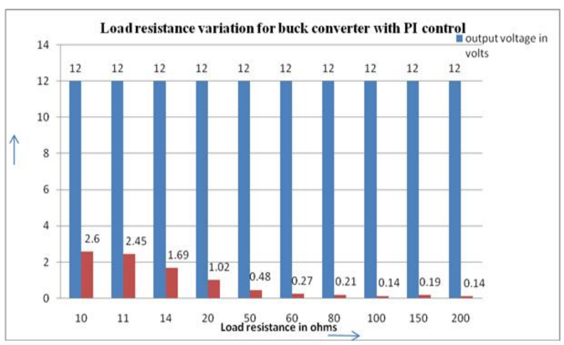

Figure: Bar graph for the variation of load resistance.

4.3. Effect of variation of line voltage on buck converter with PI control:-

When the circuit was tested under the line variation from 20 V to 34 V, it was found that as line resistance increases, load current increases settling time is almost remains constant for PI controller.

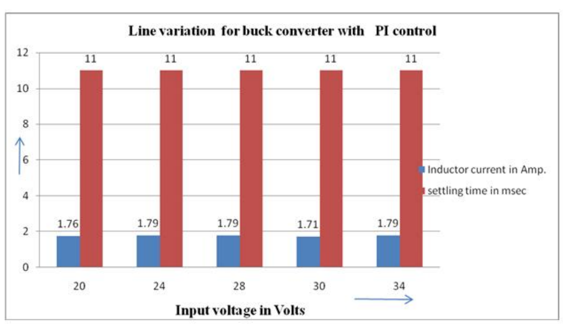

Figure: Bar graph for the line variation.

SMC Control Method

From above all control methods sliding mode control is the only non linear method and its performance is studied for comparison with other linear methods. SMC could be implemented for switch mode power supplies. The simulation controller block diagram of SMC is shown in figure.

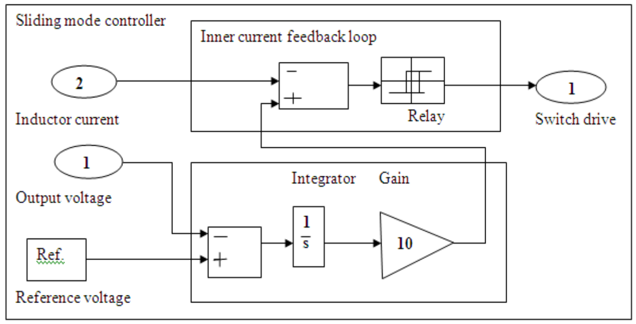

Figure: The simulation controller block diagram SMC.

5.1.1 Selection of Various Parameters for the Circuit

The control topology consists of a linear and non-linear part. The non-linear parameter can be selected, while it is left to the designer to tune the linear part and get the optimum values depending on the application. The output of the integral is amplified through a gain and the result is subtracted from the inductor loop, the difference is passed through a hysteresis. One major drawback of this model is the lack of a standard procedure to select the gain. The hysteresis parameter can be selected by measuring the peak-to-peak inductor current and these are the limits for the hysteresis parameters.

Table 2:- Main Circuit Parameters:-

Parameter name	symbol	Value
Input voltage	V_{in}	24 volts
Output voltage	Vo	12 volts
Capacitor	C	220μF
Inductor	L	69μH
Load resistance	R_L	13 Ω
Nominal switching frequency	f	100 kHz
Switch off	SW1	u= 0
Switch on	SW1	u= 1

5.2. Buck Converter with Sliding Mode Control Simulated Circuit Diagram

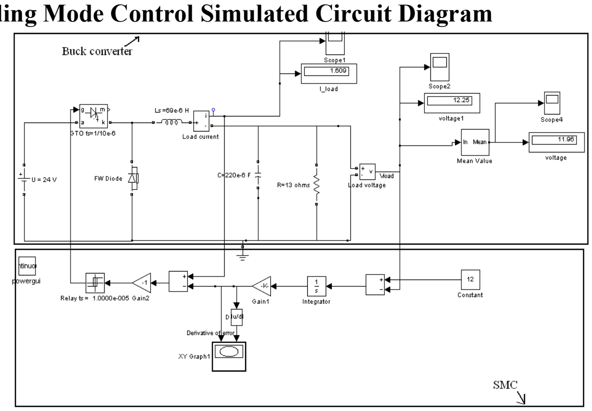

Figure: Simulation diagram for buck converter with SMC

Considering above circuit in which a buck converter when considered with SMC controller it has been observed that the circuit has settling time of 20 msec. The output voltage attends steady state value of 12 V, which is expected output from this application. Under the load variation of SMC circuit from 0 to ∞, it was found that as load resistance increases load current decreases and settling time increases continuously.

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Variation of Load Resistance on Buck Converter with SMC Control

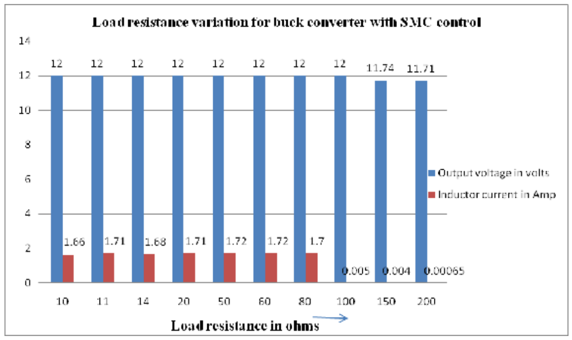

Figure: Bar graph for load resistance variation

Above bar graph shows the effect of load variation on buck converter with SMC controller. As resistance value increases inductor current decreases. For ∞ resistance voltage is 23.69 and inductor current is 1.16e-10 A. But in the range of 10 Ω to 13 Ω load resistances inductor current and load voltage almost remain constant.

VI. Performance Comparison

Table 6.1 shows the summary of the performance characteristics of the buck converter between PI, SMC controller quantitatively. Based on the data tabulated in Table 6.1, while SMC has the slowest settling time of 20 m seconds. An extra of 17.5 m seconds is required for the SMC controller for steady state voltage.

Table 6.1

Sr.No.	Type of circuit	Output voltage			Inductor current		
		Rise Time	Maximum Peak overshoot	Settling Time	Rise Time	Maximum Peak overshoot	Settling Time
1	Buck Converter	0.9 m sec	11V	4 m sec	0.9 m sec	2A	4 m sec
2	Buck Converter with PI controller	0.25 msec	25 V	6.5 msec.	0.25 msec	40 A	6.5 msec.

VII. Comparison Graph for Rise Time, Delay Time and Settling Time for All Existing Controllers

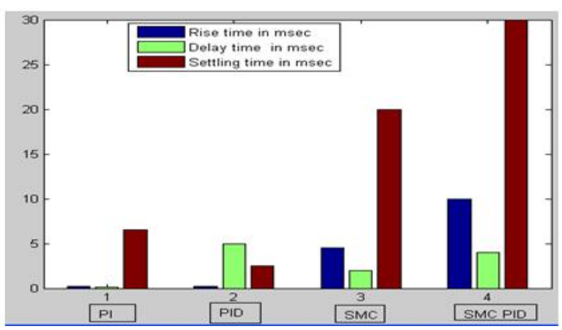

Figure: Comparative graph for all existing controllers

7.1 Comparative graph for peak overshoot, regulation, output voltage and inductor current all existing controllers:-

From comparison we can say for same output voltage and inductor current peak overshoot is maximum for PI control from the performance analysis of uncompensated buck converter we can say that because of disturbances and nonlinearities output voltage of converter is 14.12 V instead of 12 V.

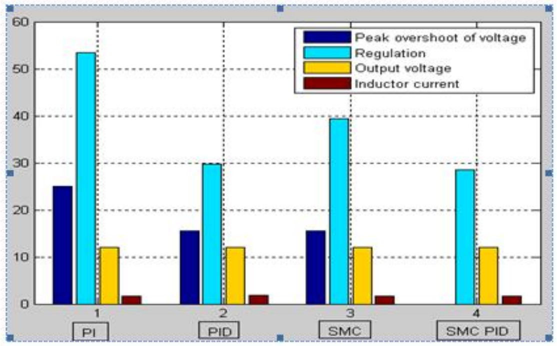

Figure: Comparative graph for all existing controllers

VIII. Conclusion

As SMC is not operating at a constant switching frequency and converters have a highly nonlinear and time varying nature therefore it is selected to control such kind of DC- DC converter. In many research it was found that SMC it is an efficient control technique for time variant system like switch mode power supply. Therefore it is also selected as control technique for performance analysis. The waveforms of simulated output voltage and current were obtained, studied and compared with the waveforms from other controllers for performance comparison. By studied references papers in details the waveforms were found to be in precise proximity of theoretical waveforms. Some concluding points which are analyzed in following points.

When buck converter is considered with PI control within 6.5 msec output voltage attends 12 V. Under the load variation of this circuit from 0 (short circuit) to ∞(open circuit), it was found that as load resistance increases load current decreases and settling time increases continuously. In range of resistance 10 Ω to 13 Ω output voltage and inductor current was found to be almost constant

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