ISSN: 2277 – 9043
International Journal of Advanced Research in Computer Science and Electronics Engineering
Volume 1, Issue 6, August 2012

State Space Analysis and Modeling of DC-DC Converter With High Frequencies

A. Suresh Kumar / Assistant Professor, Dept. of EEE**,** RGMCET, Nandyal

M.Sreenu / P.G.Student Dept. of EEE**,** RGMCET, Nandyal

ABSTRACT

The design of the control law for power converter can be a complex task especially when high performance is required against load and line variations. This difficulty can further increase in the presence of input filters. Which are intentionally under damped to decrease the converter losses. In such cases, the peak current mode control facilitates the design of control law. The usual approach for the modeling of this type of control assumes constant current ripples in smoothing inductance. However, this assumption is somewhat restrictive and limits the validity of the model at high frequency. This paper presents a modeling approach which avoids this assumption, consequently leading to a better representation of the converter at high frequencies. In order to improve its performance with respect to load and line disturbances, this kind of control implicitly integrates a feed forward compensation. The application of the developed analysis is carried out on a buck converter; however, it is equally applicable to any other type of converter. Finally the results are simulated in MATLAB/Simulink environment.

Keywords: *Power converter, Control Schemes (VCM, CCM, Peak Current Mode Control PCMC) MATLAB/Simulink.*

I. INTRODUCTION

The dc-dc converters can be viewed as dc transformer that delivers a dc voltage or current at a different level than the input source. Electronic switching performs this dc transformation as in conventional transformers and not by electromagnetic means. The dc-dc converters find wide applications in regulated switch-mode dc power supplies and in dc motor drive applications. The output voltage of dc-dc converter ranges from one volt for special VLSI circuits to tens of kilovolts in X-ray lamps. The most common output voltages are 3.3V for modern microprocessor, 5V and 12V for logic circuits, 48V for telecommunication equipments and 270V for main dc bus on airplanes. The general block diagram of dc-dc converter is shown in Fig.1.1.

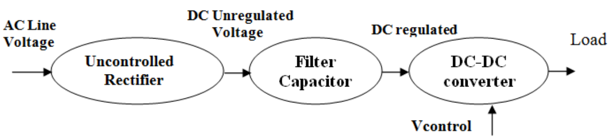

Fig 1.1 General block diagram of dc-dc converter

The unregulated dc voltage is converted into regulated dc voltage to the required level under varying load and input Voltage condition. The control of output voltage is performed in a closed loop manner using principle of negative feedback. The two most common closed loop control strategies of dc-dc converters are the voltage mode control and current mode control but by means of closed loop control the speed of response and overshooting problem is not eliminated completely and also not gives satisfactory results for large range of load variation. Dc–Dc converters are non-linear in nature. The design of high performance control for them is a challenge for both the control engineering engineers and power electronics engineers. In general, a good control for dc–dc converter always ensures stability in arbitrary operating condition. Moreover, good response in terms of rejection of load variations, input voltage changes and even parameter uncertainties is also required for a typical control scheme.

From the state-space averaged model, possible perturbations are introduced into the state variables around the operating point. On the basis of the equations, transfer functions of the open-loop plant can be obtained. A linear controller is easy to be designed with these necessary transfer functions based on the transfer function.

1.1. LITERATURE REVIEW:

There are so many papers on modeling and analysis of PWM DC-Dc converters. A variety of methods for modeling switch mode converters were developed. Of those, the most commonly used method is State Space Average (SSA) method. This method is often used to obtain average state equations, from which an equivalent circuit model can be derived. Other methods can also be used, to obtain the converter model, by replacing the converter with an equivalent circuit model. But these are typically restricted to few topologies. State space average method was commonly accepted and recognized tool in modeling and analyzing PWM DC-DC converters. But it is lagging behind many practical control applications. Some of them is the discrepancy of the true average value, when compared with their state space average is very significant. Also, the stability of the state space model does not ensure the stability of the concerned converter. These are some of the starting aspects of this study.

An alternative method for extending the averaging techniques was proposed in [1]. We all know that Fourier series can be used for analyzing the waveforms of PWM DC-DC converters. Based on this fact, a novel approach for estimating the average value of the responses of switched converters has been proposed [5]. It is a generalization of the state space average method, taking the effect of harmonics, Generalized State Space Average Method, which transforms the time varying models of the switched converters into time-invariant models, which are linear with constant coefficients. Feedback PWM converter method is first proposed in [1]-[3], where the control input was allowed to vary, so as to make the averaged model is useful regardless of switching frequency. But sensing of Inductor current along with capacitor voltage adds to cost, if the dc-dc converter is having large number of energy storage elements. If the converter is having large number of Inductors and capacitors, taking only output capacitor voltage as feedback [8] is better solution. But they tested it for very small rating (less than 5watt). We cannot even test it , because practical diode forward voltage itself is 0.7V.

The definition of Multi-converter power electronic system was discussed in [11]. But here, only Buck and Buck-boost converters were used to study the system. Also, the analysis was not based on GSSA. Only ref [7] discussed how GSSA can be used for multi-converter system.

2. STATE SPACE MODELING OF BUCK CONVERTER

A very common tool for modeling the dynamics of power electronics is averaged circuit model. The averaged model is a close approximation to the circuit model. However, the averaged circuit model may not provide a complete solution for analyzing and controlling the dynamics of power electronic circuits. Other type of model is state space models, which include switched and averaged models. These models are more general and powerful, for analyzing and controlling both steady state behavior and small perturbations from it. State space models involve state variables, which describe the behavior of the system. With these, both nonlinear and time varying models can also be handled.

2.1 LARGE-SIGNAL MODELING:

It is a common analysis method used in electrical engineering to describe nonlinear devices in terms of the underlying nonlinear equations. In circuits containing nonlinear elements such as transistors, diodes, and vacuum tubes, under "large signal conditions", AC signals have high enough magnitude that nonlinear effects must be considered.

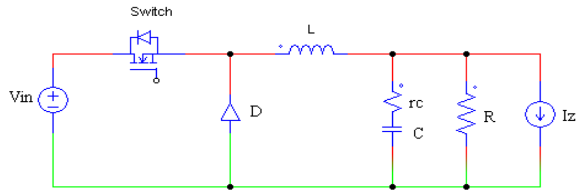

Fig 2.1. Buck Converter

State model equation of Buck converter (when it is turn ON) with large signal variations is

$$\begin{bmatrix} I \\ Vc \end{bmatrix} = \begin{bmatrix} \frac{-Rr_c}{L(R+r_c)} & \frac{-R}{L(R+r_c)} \\ \frac{R}{C(R+r_c)} & \frac{-1}{C(R+r_c)} \end{bmatrix} \begin{bmatrix} i \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} & \frac{Rr_c}{L(R+r_c)} \\ 0 & \frac{-R}{C(R+r_c)} \end{bmatrix} \begin{bmatrix} V_{in} \\ I_z \end{bmatrix} \quad \text{--- (1)}$$

State model equation of Buck converter (when it is turn OFF) with large signal variations is

$$\begin{bmatrix} I \\ V_C \end{bmatrix} = \begin{bmatrix} \frac{-Rr_C}{L(R+r_C)} & \frac{-R}{L(R+r_C)} \\ \frac{R}{C(R+r_C)} & \frac{-1}{C(R+r_C)} \end{bmatrix} \begin{bmatrix} i \\ V_C \end{bmatrix} + \begin{bmatrix} 0 & \frac{Rr_C}{L(R+r_C)} \\ 0 & \frac{-R}{C(R+r_C)} \end{bmatrix} \begin{bmatrix} V_{in} \\ I_Z \end{bmatrix} \quad \text{--- (2)}$$

The average State model equation of Buck converter is

$$\begin{bmatrix} I \\ Vc \end{bmatrix} = \begin{bmatrix} \frac{-Rr_c}{L(R+r_c)} & \frac{-R}{L(R+r_c)} \\ \frac{R}{C(R+r_c)} & \frac{-1}{C(R+r_c)} \end{bmatrix} \begin{bmatrix} i \\ Vc \end{bmatrix} + \begin{bmatrix} \frac{-d}{L} & \frac{Rr_c}{L(R+r_c)} \\ 0 & \frac{-R}{C(R+r_c)} \end{bmatrix} \begin{bmatrix} V_{in} \\ I_z \end{bmatrix} \quad \text{---(3)}$$

2.2 State space modeling large signal Buck converter:

In control engineering, a state space representation is a mathematical model of a physical system as a set of input, output and state variables related by first-order differential equations. To abstract from the number of inputs, outputs and states, the variables are expressed as vectors and the differential and algebraic equations are written in matrix form.

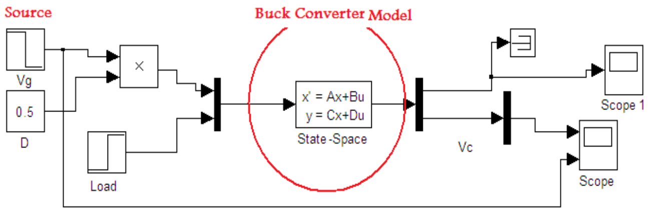

Fig 2.2 State space model of large signal Buck converter

3. Control Laws of Buck Converter

There are many different switching regulators and controllers on the market for DC to DC step down power conversion with many different control loop architectures, each offering advent-ages and disadvantages for a given power supply. An engineer not living power management every day might select a power management IC for a project without clearly understanding the advantages and disadvantages of different control topologies. There are three main groups of control topologies in DC to DC conversion. Voltage mode control, Current mode control and Average current mode control.

3.1 VOLTAGE MODE CONTROL:

It has been around for a long time. The control loop is set up so that the output voltage is compared to a reference voltage by an error amplifier. The output of the error amplifier equals the error – in other words, the amount the feedback voltage is away from the reference voltage. This error voltage is then compared to a wheeling saw-tooth voltage, and a comparator (PWM comparator) sets the duty cycle for the power switch. The advantages of this topology are that the control loop can be made relatively fast, and there is no minimum on time required. Some voltage mode ICs does require some minimum on-time, but it is very short. Keeping the advent-ages in mind, voltage mode is used in fast applications such as powering high-end computer processors and also in applications where the input voltage will be close to the output voltage. The short minimum on-time helps to achieve low dropout voltage especially at higher switching frequencies.

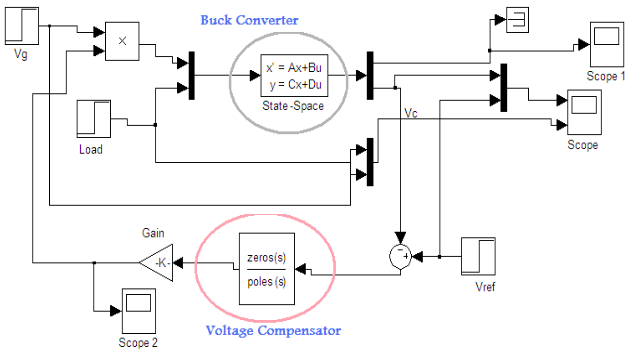

Fig.3.1.State space model of voltage mode controlled Buck converter

3.2. CURRENT-MODE CONTROL:

It is also called current programmed control and current-injected control. In current-mode control, two control loops are used as shown in Fig.3.2, the inner loop is fast and controls the inductor current, while the outer loop is slower and controls the load voltage. The inductor current is fed back via the current controller in the inner loop while the load voltage is fed back via the voltage controller in the outer loop. The voltage controller has the reference signal. The voltage controller tries to get ”$V_0(t)$” equal to “V_{ref}” by changing its control signal. This signal is subsequently used as the reference signal for the current controller. The current controller aims at getting ”$i_L(t)$” equal to “$i_c(t)$” by changing the duty ratio of the converter. Thus, current-mode control is an application of cascade control.

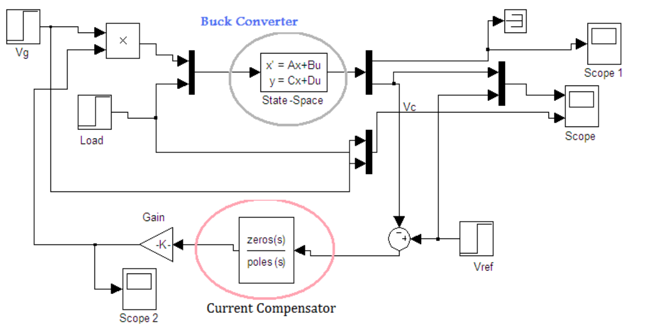

Fig 3.2: Current Mode controlledBuckconverter

3.3 PEAK CURRENT-MODE CONTROL:

The Fig. 3.3 shows the Buck dc-dc converter with peak current mode control technique, here The voltage controller, H(s), operates in a similar manner to the controller of the VMC, yielding the control signal V_c. The inductor current is sensed by the resistor R_s and multiplied by a gain A_s to give the sensed current signal, V_s= iA_sR_c. The difference between V_s and V_c is processed by the current controller. The resulting signal V_c, is then compared with the saw tooth voltage to produce a PWM signal, d, to switch the MOSFET. When the output voltage, V, deviates from V_{ref} the control.

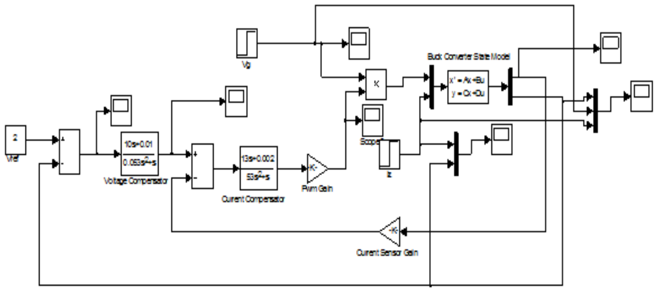

Fig.3.3.State space model PCM controlled Buck converter

4. SIMULATION RESULTS

4.1 VOLTAGE MODE CONTROLLED BUCK CONVERTER:

The figures 4.1 to 4.5 represent Output voltage when Load is disturbed, output voltage against source change, Output Voltage and Reference Voltage Dynamics, Output voltage when more disturbances at load and duty cycle variations respectively for Voltage controlled Buck converter.

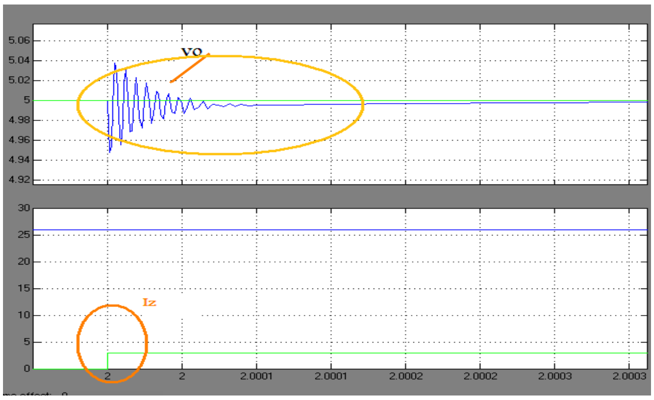

Fig.4.1. Output voltage when Load is disturbed

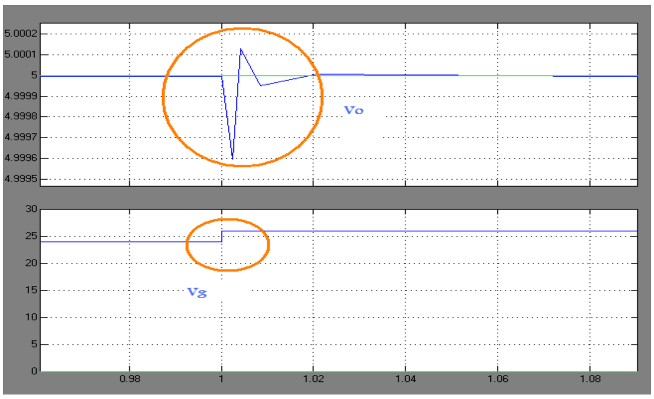

Fig. 4.2 Output voltage against source change

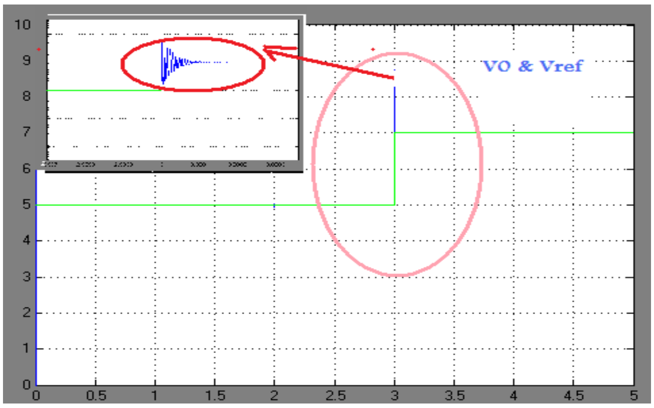

Fig. 4.3. Output Voltage and Reference Voltage Dynamics

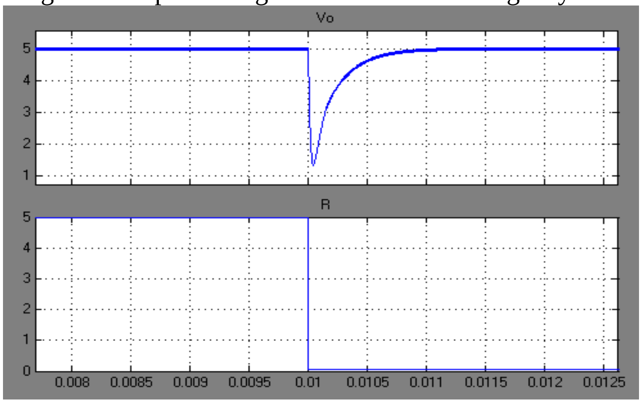

Fig.4.4. Output voltage when more disturbance at load

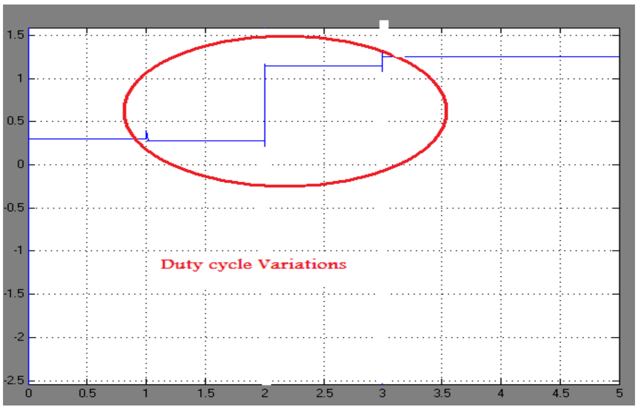

Fig.4.5. Duty cycle variations against load changes

4.2 Current Mode Controlled Buck Converter:

The figures 4.6 to 4.8 represent Output voltage when Load is disturbed, output voltage against source change, Output Voltage and Reference Voltage Dynamics, Output voltage when more disturbances at load and duty cycle variations respectively for Current mode controlled Buck converter.

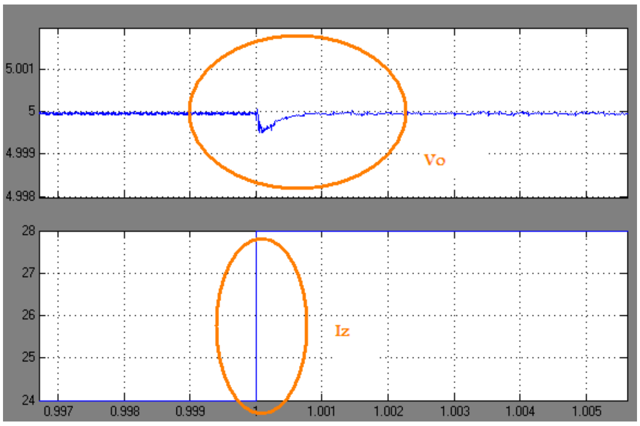

Fig.4.6. Output voltage when Load is disturbed

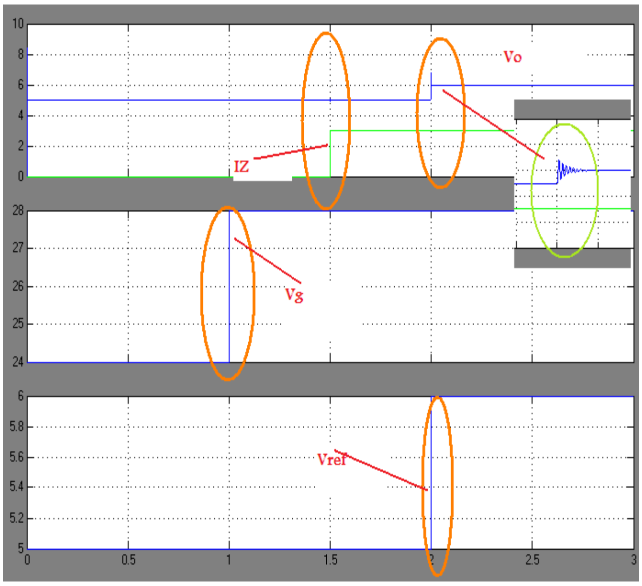

Fig. 4.7. Output voltage against source& Reference change

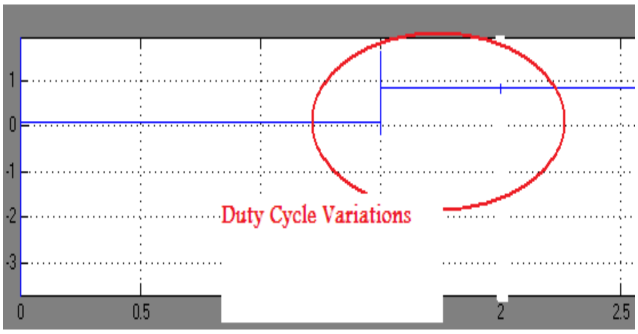

Fig. 4.8 Duty cycle variations against load changes

3.3 Peak Current Mode Controlled Buck Converter:

The figures 4.9 to 4.11 represent Output voltage when Load is disturbed, output voltage against source change, Output Voltage and Reference Voltage Dynamics, Output voltage when more disturbances at load and duty cycle variations respectively for Average current mode controlled Buck converter.

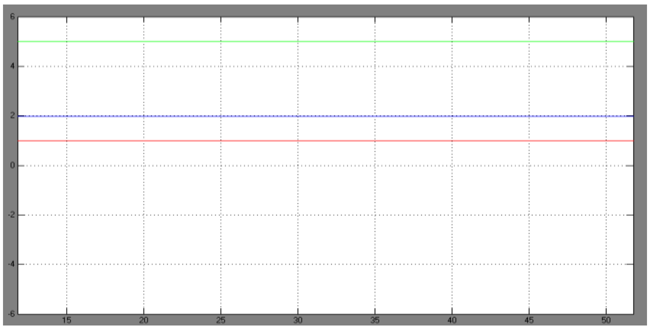

Fig. 4.9. Output Voltage against Load Current Change

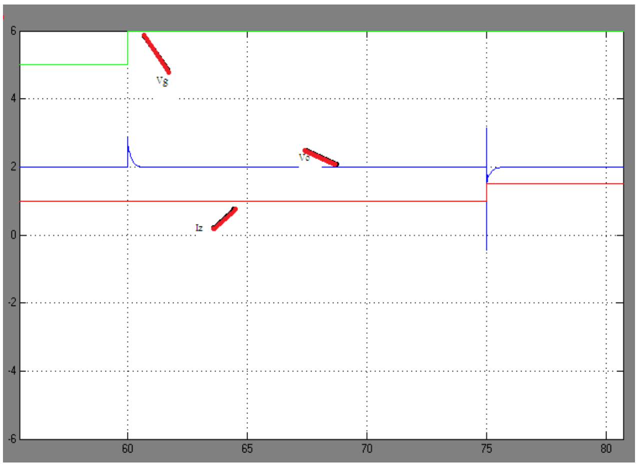

Fig 4.10.Output Voltage, Source Voltage & Load changes

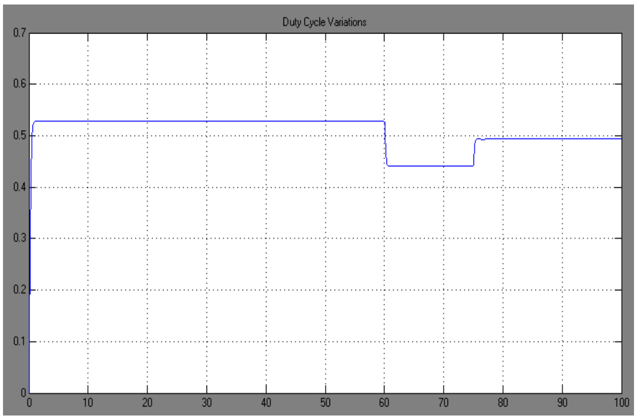

Fig 4.11. Duty Cycle Variations against Load Changes

The following table gives the comparison between the different control schemes used in Buck converter.

Considerations	Control Methods		
	Voltage Mode	Current Mode	Peak Current Mode
Design	Single loop	Double loop	Double loop
Transient response	More complex	Less complex	Less complex
Compensation techniques	Requires extra circuitry	Inherent in operation	Inherent in operation
Noise immunity	Good	Poor at low loads	Poor at low loads
Operation at duty cycle >50%	Operates normally	Requires slop compensation beyand50% duty cycle	Requires slop compensation beyand50% duty cycle
Pulse by Pulse current limiting	Requires current limiting circuitry	Inherent in Operation	Inherent in Operation
Loop gain change with VIN	Requires VIN feed forward circuit	No gain change	No gain change

Table.1: Comparison of Different control schemes

In current mode control pulse by pulse current protection mechanism is there inside the control IC because of this fact the inductor current variation is small as compared to the voltage mode control.

Conclusion

The paper mainly describes about the voltage, current and peak current mode control of BUCK dc-dc converter. Simulation models were developed for both the control methods and simulated the closed loop systems in MATLAB/ SIMULINK simulator.

The State-Space Control models of a buck converter with VMC,CMC & PCM have been presented. Though the controller used are linear the models, nevertheless are nonlinear because they constitute the nonlinear power stage control laws. These average models can predict with good accuracy than dynamic performance the converter under the step-load disturbances, validating their effectiveness in large-signal simulation. When suitably applied, the developed models may be used to facilitate the design of modem DC-DC converter modules.

References

[1] D. Maksimovic, A. M. Stankovic, V. J. Thottuvelil, and G.C. Verghese, "Modeling and simulation of power electronic converters," Proceedings of IEEE, vol. 89,issue. 6, pp. 898-912, 2001.

[2] R. W. Erickson and D. Maksimovic, Fundamentals of Power Electronics, 2nd ed., Kluwer Academic Publishers,ch. 7, 2001.

[3] A. J. Forsyth and S. V. Mollov, "Modeling and control of DC-DC converters," Power Engineering Journal, vol. 12, issue 5, pp. 229-236, 1998.

[4] T. Dabney and T. Harman, The Student Edition of SIMULINK, Prentice Hall, 1998.

[5] R.D. Middlebrook and S. Cuk "A General Unified Approach to modelling Switching-converter Power Stages," IEEE Power Electronics Specialists Conference Record, 1976, pp. 18-34.

[6] H. Chung, "Design and analysis of quasi switched-capacitor step-up dc/dc converters," in *Proc. IEEE Int. Symp. Circuits and Systems*, 1998, pp. 438–441.

[7] R. Schumann, M. S. Ghausi, and K. R. Laker, *Design of Analog Filters: Passive, Active RC, and Switched Capacitor*, 1990.
[8] W. Lim, B. Choi, and J. KO, "Current-mode control to enhance Closed-loop performance of asymmetrical half-bridge dc-to-dc conveners," *in Proc. WAS*, 2004, pp. V-896-899.
[9] R. Mammano, "Switching power supply topology: Voltage mode -vs- current mode," in *Unitrode Applications hand book, 1997.*
[10] Unitrode's power supply circuits data book.

A.Suresh Kumar was born in kurnool, India. He received the B.Tech (Electrical and Electronics Engineering) degree from the Jawaharlal Nehru Technological University, Hyderabad in 2005; M.Tech (Power Electronics & Drives) from the Veluru Institute of Technology in 2008.He is currently an Asst.Professor of the Dept. of Electrical and Electronic Engineering, R.G.M College of Engineering and Technology, Nandyal. His area of interest power electronics and Electric Drives and Resonant converters.

M.Sreenu **was born inVinjamur (md)**, **SPSRnellore (dt),** India. He received the B.Tech (Electrical and Electronics Engineering) degree from the Acharya Nagarjuna University, Guntur, in 2009. Currently perusing M-Tech (power Electronics), in Rajeev Gandhi Memorial College of Engg.&Tech,Nandyal.